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Special Issue Reprint

Smallholder Farming under External Shocks

New Perspectives and Solutions for Future Crises

Edited by
Emmanuel Olatunbosun Benjamin, Gertrud Buchenrieder and Oreoluwa Ola

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Preface

This reprint or Special Issue (SI) focuses on exploring the adaptive and coping strategies employed by smallholder farmers in various landscapes affected by external shocks, specifically climate change, the COVID-19 pandemic, and the Russo-Ukrainian war. These shocks directly affect agricultural productivity via the increased frequency of extreme weather events or disrupted supply chains for inputs like fertilizer or feed. As a result, the environmental, social, economic (sustainability), and biodiversity benefits provided by these systems are hindered. The SI presents a comprehensive overview of theoretical, empirical, and field-research-based evidence from both developing and developed countries, highlighting lessons learned and the applicability of diverse strategies in building crisis-resistant food systems in urban and rural areas. The primary objectives of this reprint or Special Issue (SI) are to provide insights into the impacts of external shocks, such as climate change, the COVID-19 pandemic, and the Russo-Ukrainian war on smallholders engaged in agriculture, agroforestry, and aquaculture in urban and rural areas. This SI also aims to explore the adaptive and coping strategies adopted by smallholders, as well as government policies and measures aimed at mitigating the impact of these shocks and evaluating their effectiveness.

Emmanuel Olatunbosun Benjamin, Gertrud Buchenrieder, and Oreoluwa Ola
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Article

Local Observations of Climate Change and Adaptation Responses: A Case Study in the Mountain Region of Burundi-Rwanda

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Abstract: Mountain regions and their communities are particularly vulnerable to climate change impacts. However, little is known on the impacts observed and adaptation responses used in Burundi's mountain region and if these are different to those reported in the contiguous mountain region of Rwanda. This paper aims to fill in these knowledge gaps. Semi-structured interviews were conducted with 300 smallholder farmers, 150 in northern Burundi and 150 in southern Rwanda. Farmers in both countries reported negative impacts on crops, animals, and human health, with small differences between countries driven by the main cultivated crops. More adaptation strategies were used in Burundi than in Rwanda, and more farmers in Burundi were using multiple strategies. In both countries, farmers' wealth affected farmers' adaptation responses and their food security. Notably, for all wealth groups (poor, average, rich), food security was lower in Rwanda than in Burundi. We relate our findings to current agricultural intensification policies in both countries and argue for the greater involvement of local farmers in adaptation planning using, for example, science-with-society approaches.

Keywords: adaptation strategies; African mountains; farmers; food security; perceptions; wealth groups

1. Introduction

Predicted changes in climate, including increased temperatures and changing rainfall patterns, are expected to threaten food production and intensify food insecurity across Sub-Saharan Africa [1]. Mountain regions and their communities are particularly vulnerable to climate change impacts because the rate of warming is amplified with elevation [2]. The latest IPCC Cross-Chapter on Mountains highlights how climate change impacts have increased in recent decades with observable and serious consequences for people and ecosystems in many mountain regions, including in Africa [3]. This Cross-Chapter also warns that with warming above 1.5 °C, adaptation becomes more and more urgent in mountain regions [3].

In mountain regions, like in other regions with complex topography, there is still considerable uncertainty about the local and regional environmental consequences of the changing climate because of the limited spatial resolution of global climate models [4]. In such regions, climate change observations or perceptions from subsistence-oriented communities can help not only document the multiple fine-scale environmental consequences of climate change but also design effective adaptive strategies [5,6]. It is known that climate change perception is a complex process that encompasses a range of psychological constructs such as knowledge, beliefs, attitudes, and concerns about if and how the climate is changing [7]. Perception is influenced by individuals' characteristics, their experience, the information that they receive, and the cultural and geographic context in which they live, among other factors [7,8]. Notably, the perception that farmers have about climate change is a key component to understanding their adaptation decisions [9]. Apart from perceiving that the climate is changing, farmers also have to give enough weight to this perception to take action [10].

In Sub-Saharan Africa, most research on climate change observations by subsistence-oriented communities and farmers' adaptation responses in mountain regions has been conducted in East Africa [3], in particular in Tanzania [11]. Much less is known about the Albertine Rift, the western branch of the East African Rift, which covers parts of Uganda, Rwanda, Burundi, DR Congo, and Tanzania. The Albertine Rift is a climatically complex region comprising both bimodal and unimodal rainfall regime zones, as well as important rain shadow effects related to irregular topography [12]. Recent work from Uganda [12–15], Rwanda [16,17], and DR Congo [18,19] has increased our understanding of climate change impacts and farmers' adaptation responses for this region, but limited information is still available from Burundi. A recent analysis of rainfall amounts and distribution over Burundi revealed decreasing trends for both annual and seasonal rainfall, including in the mountainous region of this country [20], and an increase in extreme wet and dry events, particularly since the early 2000s [21]. These authors highlighted that extreme wet and dry events often lead to crop failure and socioeconomic losses, but they provided no details on the impacts on different crops nor on the adaptation strategies implemented by smallholder farmers.

Smallholder farmers can employ a wide range of adaptation strategies, including: (i) ex-ante (decisions made prior to a growing season to minimise risks), (ii) in-season (responses to perceived and forecasted weather conditions that drive adjustments to crops or cultivation practices), and (iii) ex-post (responses implemented to reduce the negative impacts of climate shocks which have already occurred) [22]. Adaptation strategies can also be clustered into two groups: on-farm and off-farm strategies. The most common on-farm strategies are the maintenance of high agrobiodiversity—to spread the risk of crop failure among species (or varieties) which are susceptible to different climatic stresses—and soil or water conservation practices [23]. Two of the most prominent off-farm strategies are off-farm labour and membership in farmers' organisations, which can facilitate improved seeds, inputs, credit and subsidies, or technical support; see [24]. For example, over 20 different adaptation strategies are used by Tanzanian mountain farmers [11]. In general, as wealthier households have greater access to land, more resources to invest in irrigation or inputs and/or better access to information and technologies, they tend to employ a wider range of adaptation strategies [11].

Recent work from Rwanda has highlighted that agricultural intensification policies can also affect farmers' adaptation, with positive or negative effects depending on household wealth [17,25]. The Crop Intensification Program (CIP) of Rwanda, implemented in 2008, aims at increasing agricultural productivity through the promotion of hybrid seeds and the increased use of agrochemicals and agro-engineering techniques, such as draining marshland and constructing terraces [26]. Through performance contracts, households submit written agreements in which they state that they will cultivate selected crops several months before the growing season begins. The farmers failing to meet their contracts or found planting non-approved crops can be publicly disgraced and even penalised [17]. The CIP discourages seed sharing between farmers, the cultivation of multiple small fields located at different elevations, polyculture, and the cultivation of certain crops such as sweet potato, cassava, ciraza, or sorghum [26]. Although polyculture contributes to households' food security throughout the year (for example, while cassava is ripening, beans can be eaten, see [27]), sweet potato, cassava, ciraza, and sorghum are perceived by local farmers as being more drought- and flood-tolerant crops than the government-approved maize or beans [25]. Although the CIP has raised crop yields, and the conventionally measured poverty rates have fallen in Rwanda in the past few years, some authors have highlighted that such agricultural intensification policies appear to be exacerbating rural landlessness, inequality, and food insecurity [27].

In Burundi, no such 'Crop Intensification Program' exists, but there is a political willingness to boost and intensify the agricultural sector. A priority of the National Agricultural Strategy (2008–2015) was the strengthening of the hybrid seed sector, through the creation in 2013 of the National Seed Control and Certification Office (*Office National de Contrôle et de Certification des Semences, ONCCS*), which was expected to boost access to and the use of improved seeds by smallholder farmers [28]. The government has also been investing in increasing farmers' access to fertilisers through the creation of a local company manufacturing organo-mineral fertilisers. Since October 2021, zero-grazing for cattle has also been promoted, with the aim of both increasing access to manure and reducing rangeland degradation (Loi N°1/21 du 4 Octobre 2018). Although these policies focus on intensifying agricultural production, contrary to Rwanda, in Burundi, there is no strict control of farmers' crop choices, so farmers may continue to practice polyculture and/or experiment with different crops (or varieties) in different seasons or years.

The mountainous region of the Congo–Nile Divide of northern Burundi and southern Rwanda offers a unique opportunity for the investigation of the effects of agricultural intensification policies on smallholder farmers' capacity to adapt to climate change. The inhabitants of both countries are from the same ethnic groups, so cultural differences, known to affect farmers' adaptation [18,19], are unlikely to be an important driver of differences in adaptation across countries. This paper aims to: (1) identify the observed changes in the climate and their impacts on the biophysical system as perceived by these farmers in northern Burundi and southern Rwanda; (2) determine which strategies they are using to adapt and who is promoting them; and (3) investigate differences in adaptation strategies and food security across wealth groups. We adjust the framework proposed by [29], in which changes in the climate itself and the impacts of climate change observed (in the physical, biological, and social systems) are differentiated. We adhere to the Framework Convention on Climate Change [30] and use climate change to refer to a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties, and that persists for an extended period. Similar to [31], we use the term local observations of climate change to refer to reports provided by local peoples about changes in the climatic system (i.e., temperature, precipitation, and wind).

We hypothesise that small differences in perceptions of climatic changes and impacts across countries will be found as both study areas are part of the same mountain range, but that larger differences in adaptation will be observed, due to divergent agricultural intensification policies affecting farmers' choices. We also hypothesise that richer households would be using more adaptation strategies and would have higher food security. This study contributes to the field with two novel aspects: (i) it is the first to document climate change impacts and adaptation strategies in Burundi's mountains, and (ii) it is the first to investigate the effects of different agricultural intensification policies on climate change adaptation of the same ethnic group.

2. Materials and Methods

2.1. Study Areas

This study was conducted with smallholder farmers living in the Congo–Nile Ridge mountainous region of northern Burundi and southern Rwanda in the Albertine Rift. In this region, the elevation ranges from about 1300 m to 2900 m asl. The region includes the montane forests of the Kibira National Park (Burundi) and the Nyungwe National Park (Rwanda), which are contiguous (Figure 1). The region has a bimodal rainfall regime with long rains in February–June and short rains in September–December [32]. Rainfall and temperature vary with topography. Around Kibira, the annual rainfall ranges between 1700 and 2000 mm [33], whereas around Nyungwe, the annual rainfall is about 1800 mm [32]. In the region, metamorphic bedrock is overlain by highly acidic soils low in nitrogen [34]. Nyungwe forest soils have been developed mainly from schists, mica schists, quartzitic schists and granites [34].

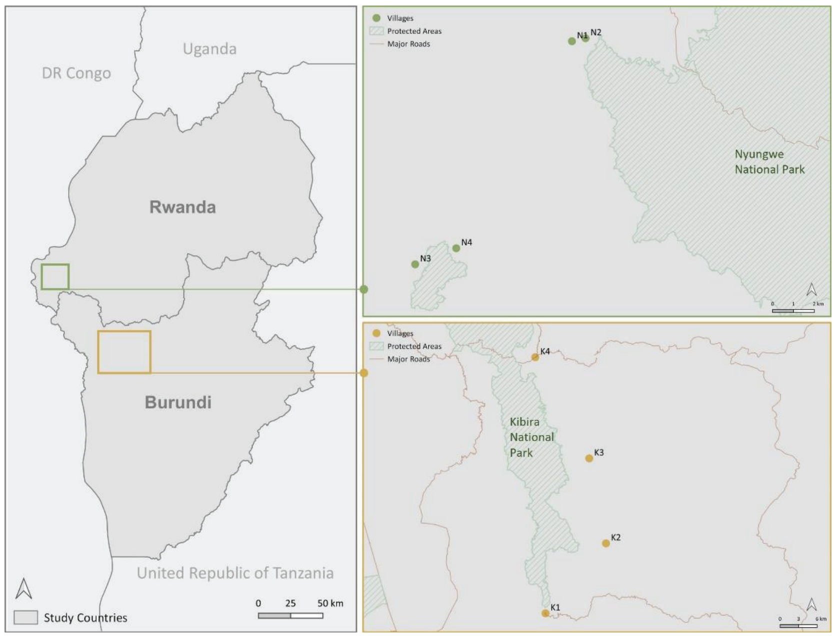

Figure 1. Study areas with the location of the villages sampled.

Local communities living in this mountainous region are farmers of Bantu origin and Twa hunter-gatherers of Pygmy origin. Our study focuses on farmers of Bantu origin. These farmers rely on rain-fed agriculture for their livelihoods, but they might also raise animals, typically pigs or cows. Cows hold high value in the local culture (for example, they are used as a dowry in marriage and are also a symbol of wealth and prestige). Tea is often grown as a cash crop in large plantations where smallholder farmers can work as labourers, but some farmers also have a few tea bushes on their farms. In Burundi, all tea is sold through the Burundi Tea Office (*Office du Thé du Burundi*), whereas in Rwanda, several tea cooperatives organise the trade of tea.

The area around Kibira has a high population density: 475 people per km^2 [35]. The average farm size is less than 1 hectare, and the main crops are maize, bush beans, Irish potatoes, and sweet potatoes [36]. The area around Nyungwe also has a high population density: 336 people per km^2 [37]. The average farm size is also less than 1 hectare, and the main crops are maize and climbing beans [38]. Although maize porridge (named *Ubugali bw'ibigori* or *Umutsima w'ibigori* in Kirundi) and beans are the main staple food for farmers around Kibira (pers. Obs. 2021), this is not the case around Nyungwe, as maize porridge is not traditionally consumed in Rwanda [38].

2.2. Data Collection and Analysis

In both study areas (the Kibira area in Burundi and the Nyungwe area in Rwanda), four villages located at different elevations were surveyed (Figure 1). These were selected based on accessibility by road and close proximity to the park boundary. In each village, we first conducted exploratory focus group discussions (FGDs) with 4–5 elders. These discussions were used to adapt a common semi-structured questionnaire to each study context and to build trust among community members. During the FGDs, we also gathered information on agents of change promoting some adaptation strategies in the village (the government, NGOs, or local communities without external support). Then, in each village selected, we conducted semi-structured questionnaires to 37–38 randomly selected household heads aiming to interview about 50% male and 50% female household heads (n = 150 in total per study area). In each village, households were selected by walking the main street and selecting every third household to the right. If the household head was not available, the next-door neighbour was targeted. We first interviewed the household head who opened the door (male or female), until we reached the targeted gender quota for that village, and then we asked to interview the other gender in the subsequent households.

Questionnaires addressed household characteristics and assets, climatic changes observed, impacts on the biophysical domain, adaptive strategies used to cope with or adapt to observed changes, household food security, food quality, and access to clean water during the previous year (see Supplementary Material). The methodological approach (first FGDs, then questionnaires in the same villages) and the questionnaire used follow the guidelines of the project Local Indicator of Climate Change Impacts, a project focused on providing data on the contribution of local and indigenous knowledge to climate change research (see [39]). The same approach has been used to survey smallholder farmers in other mountainous regions of Africa [11,19,40].

The exploratory FGDs and the interviews were carried out in Kirundi (Burundi) or in Kinyarwanda (Rwanda) and were facilitated by the first two authors between April and August 2021. All study participants (FGDs and interviews) were selected on a voluntary basis and were first informed that the aim of the study was to better understand climate change impacts and adaptation practices. The percentage of respondents per study area (Burundi or Rwanda, 150 respondents at each site) was the main unit of analysis. First, we explored differences across study areas (Burundi versus Rwanda), and then we explored differences within the study areas by pooling respondents into wealth groups (poor, average, wealthy) based on a wealth index created from ten asset indicators [41,42]. The ten assets were identified by the FGDs in each country. Assets which varied most across the households (over 25% of households did not own them) were weighted 0.25 greater than those more commonly found. In Burundi, the ten assets considered were (in increasing order of being common): a motorbike (1.3% of the respondents), >3 ha of land (4%), a high-quality house (concrete floor) (6%), a shop (6%), >1 ha Eucalyptus plantation (6.6%), solar panel (23.3%), at least 1 cow (32.6%), at least 1 pig (54%), a radio (71.3%), and being a homeowner (92%). In Rwanda, the ten assets considered were (in increasing order of being common): an android phone (1% of the respondents), a car (3%), a motorbike (3%), a shop (5%), an extra house to rent (7%), >1 ha land (9%), >5 cows (11%), a TV (41%), a radio (44%), and a 'nice floor' (cement, tiles, or local plaster 55%). In Rwanda, all respondents owned their homes.

Cross-tabulation tables and chi-square tests were used to determine significant relationships between wealth groups and adaptation strategies, following [11]. We used the wealth group as an explanatory variable and adaptation strategies as response variables. We used a significance level of $p < 0.05$. SPSS v28 was used for all data analysis.

3. Results

3.1. Household Characteristics and Assets

Some differences were observed in the household characteristics across the countries (Table 1). In Burundi, the average household size was larger, but the average farm size was smaller than in Rwanda. Additionally, poor households in Burundi owned no large animals, and most rich households relied on farming, whereas this was not the case in Rwanda, where even poor households owned large animals, and few rich households relied on farming. In terms of schooling, 66% of the respondents in Burundi had never finished primary school, whereas this was 29% in Rwanda.

Table 1. Household characteristics of the participants in this study. Large animals referred to pigs (54% and 53% of the respondents in Burundi and Rwanda, respectively), cows (32% and 31%), or goats (0% and 1%).

Burundi		**Adults**	**Farm (ha)**	**Large Animals**	**Main Activities**	**Wealth Items**
Poor	n = 19	2.6	0.26	0%	79% farming	<4 items
Average	n = 108	2.7	0.5	37%	100% farming	4–5 items
Rich	n = 23	3.6	1.86	74%	100% farming	>5 items
Rwanda		**Adults**	**Farm (ha)**	**Large Animals**	**Main Activities**	**Wealth Items**
Poor	n = 44	1.7	0.45	54%	72% farming	none
Average	n = 88	1.8	0.73	54%	60% farming	1–4 items
Rich	n = 18	1.6	1.5	72%	22% farming	>4 items

3.2. Climatic Changes Observed and Impacts

In general, similar climatic changes were reported by farmers in both countries. Most respondents (>60%) reported increased temperatures during both dry and rainy seasons, the late onset of the long rains, more dry spells during the long rains, fewer foggy days, and fewer hailstorms (Figure 2). More respondents in Burundi mentioned an increase in extreme floods due to an increase in both heavy rains and local deforestation, whereas more respondents in Rwanda highlighted an increase in showers during the dry season (Figure 2).

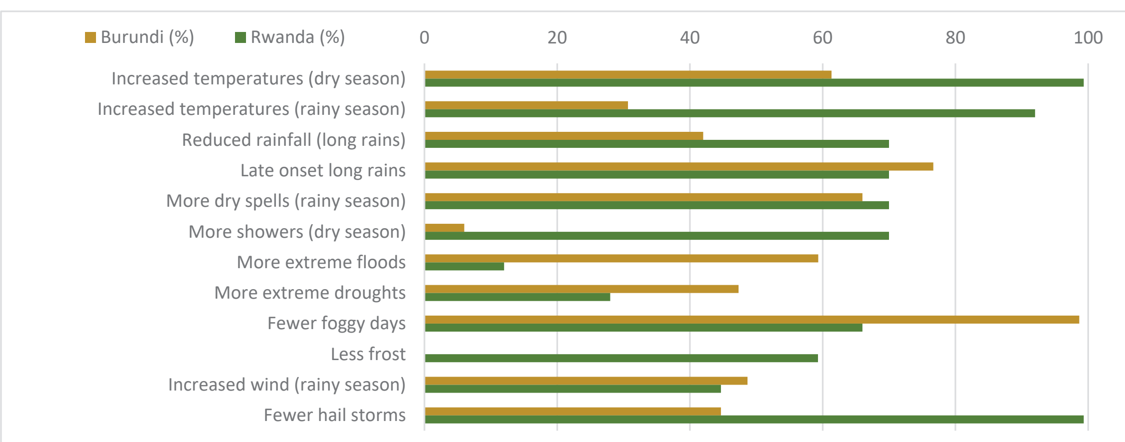

Figure 2. Observed changes in climate in terms of the percentage of respondents in each study area (Burundi n = 150, Rwanda n = 150). Note that we did not ask about reduced rainfall during the short rains, but some respondents in both countries mentioned such changes, something which requires further investigation.

Similar impacts in the biophysical domain were also reported by farmers in both countries. Numerous respondents (>40%) reported more landslides, a reduction in maize and beans' yields, an increase in pests and diseases for these crops (particularly fall armyworm for maize and rust and sooty mould in beans), and that people were overall less healthy (Figure 3), which was attributed to an increase in malaria prevalence and influenza in

Burundi (in Rwanda, the respondents did not specify a particular disease). Some respondents also reported reduced cow milk production and an increase in livestock diseases, particularly foot-and-mouth disease (Figure 3). About 20% of the respondents (which is all the households in Burundi and Rwanda engaged in tea farming) reported a reduction in tea-leaf yields, which they attributed to an increase in tea mosaic virus.

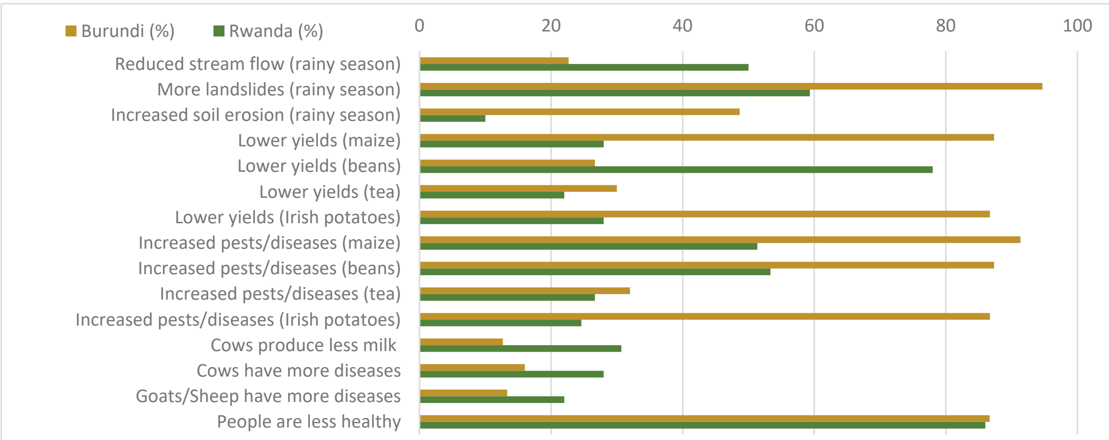

Figure 3. Observed impacts in the biophysical domain regarding the percentage of respondents in each study area (Burundi n = 150, Rwanda n = 150).

The main differences across the countries were that in Burundi, the most-cited impacts were more landslides and lower yields of maize and Irish potatoes, whereas in Rwanda, the most-cited impacts were lower yields of beans (note that in the study area in Rwanda, beans are the main crops promoted by the government).

3.3. Adaptation Strategies

Study respondents in both countries reported mainly using on-farm adaptation strategies (Figure 4), including ex-ante (for example, using improved seeds), in-season (for example, sowing seeds twice if they die), and ex-post (for example, selling firewood), Whereas 23 adaptation strategies were reported in Burundi, 17 were reported in Rwanda. In general, most respondents in both countries had increased the use of improved varieties (particularly early maturing maize), inputs (fertiliser, pesticide), irrigation, and soil conservation techniques (Figure 4). Over 40% of the respondents had also diversified into paid labour outside the household or into animal rearing. Notably, for most strategies, a larger percentage of farmers in Burundi than in Rwanda were reporting using those strategies, which could be related to their greater freedom of choice for experimenting.

Some important differences were also observed between countries: changing farm location (to the vicinity of a stream in order to be able to irrigate), growing new crops, and sowing seeds earlier (due to uncertainty in rainy season length) were mentioned by more farmers in Burundi, whereas the use of terraces and veterinary care and diversifying into vegetable or fruit production were cited by more farmers in Rwanda (Figure 4). Both in Burundi and Rwanda, irrigation refers to hand-made canals which are often individually managed—except in one village in Burundi in which they were collectively managed. In both countries, the use of chemical fertilisers and pesticides is promoted and subsidised by the government.

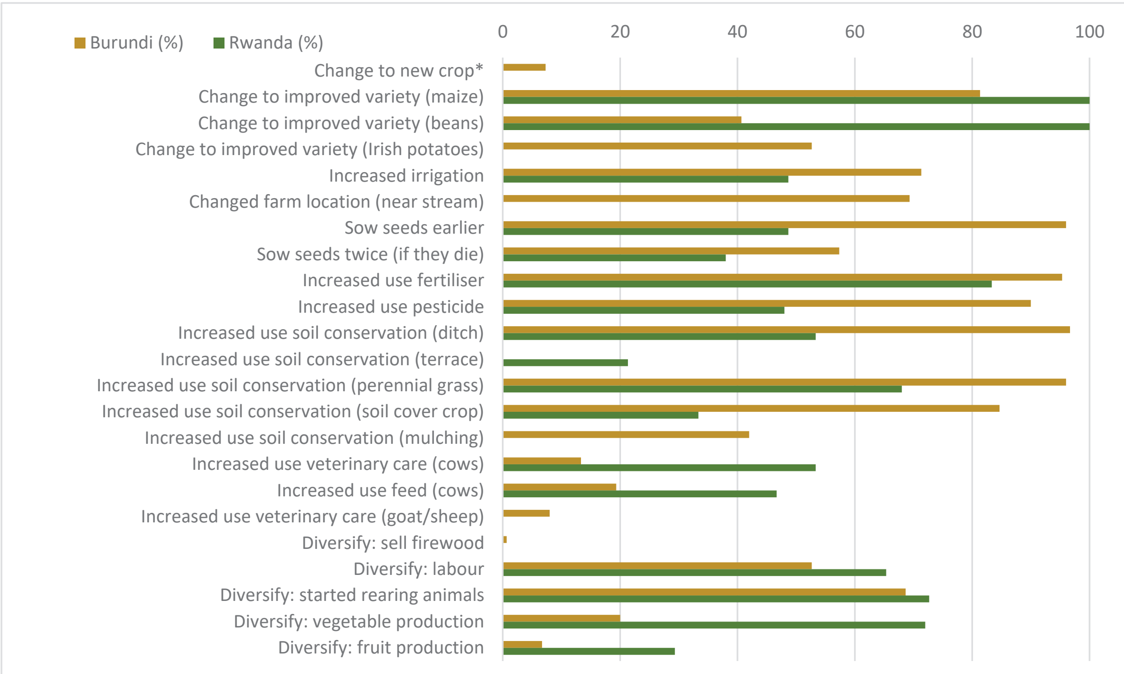

Figure 4. Adaptation strategies used regarding percent of respondents in each study area (Burundi n = 150, Rwanda n = 150). * New crops refer to sweet potatoes, cassava, or wheat. Note that we did not ask about improved Irish potatoes in Rwanda.

In Burundi, most strategies had been initiated by local farmers except the use of improved maize (promoted by an NGO) and soil conservation techniques (promoted by government extension services). In Rwanda, most strategies had been initiated by the government or NGOs enforcing the same choices of the government, including improved varieties, the increased use of inputs, soil conservation techniques, veterinary care for cattle, and supplementary feed for cattle.

In Burundi, the respondents obtained improved seeds from the market (41.6%), farmers' associations (37.3%), or from buying them from ISABU (*Institut des Sciences Agronomiques du Burundi*, 14%), whereas in Rwanda, farmers obtained improved seeds from the market (58%) or from an NGO (26%). In both countries, over 95% of the respondents relied on their own traditional ecological knowledge to determine when to sow their crops.

3.4. Wealth Effects on Adaptation and Food Security

Wealth had a significant effect on the adaptation strategies used in both countries ($p < 0.05$). These effects were more evident in Burundi, where fewer poor farmers used improved seeds, irrigation, and pesticides or diversified into animal rearing or vegetable farming but engaged more in labour (Table 2). In Rwanda, fewer poor households used pesticides or soil conservation techniques or invested in fruit farming compared to richer households (Table 3).

Table 2. Differential adaptation responses by wealth groups by farmers around Kibira, Burundi (n = 150). % refers to the % of respondents within each wealth group. Bold refers to significant differences across wealth groups at $p < 0.05$, using cross-tabulation tables and chi-square tests.

	Rich (%)	**Average (%)**	**Poor (%)**
Changed to new crop	**0**	**10.1**	**0**
Change to improved variety (Irish potato)	73.9	51.9	**31.6**
Change to improved variety (maize)	82.6	87.0	**47.4**
Change to improved variety (beans)	43.5	38.9	47.4
Increased irrigation	73.9	74.1	**52.6**
Changed farm location (near stream/swamp)	65.2	75.9	**36.8**
Sow seeds earlier	100.0	96.3	89.5
Sow seeds twice (if they die)	56.5	57.4	57.9
Increased use fertiliser	95.7	96.3	89.5
Increased use pesticide	100.0	90.7	**73.7**
Increased use of soil conservation (diversion ditch)	95.7	98.1	89.5
Increased use of soil conservation (perennial grass)	100.0	97.2	84.2
Increased use of soil conservation (soil cover crop)	100.0	85.2	63.2
Increased use of soil conservation (mulching)	47.8	41.7	36.8
Increased use of veterinary care (cattle)	30.4	12.0	0.0
Increased use of feed (cattle)	34.8	19.4	0.0
Increased use of veterinary care (other animals)	13.0	6.5	10.5
Diversify: labour	17.4	57.4	**68.4**
Diversify: animal rearing	87.0	71.3	**31.6**
Diversify: vegetable production	21.7	20.3	**15.7**
Diversify: fruit production	4.3	7.4	5.0

Table 3. Differential adaptation responses by wealth groups by farmers around Nyungwe, Rwanda (n = 150). % refers to the % of respondents within each wealth group. Bold referes to Significant differences across wealth groups at $p < 0.05$, using cross-tabulation tables and chi-square tests.

Rwanda	**Rich (%)**	**Average (%)**	**Poor (%)**
Increased irrigation	33.3	46.6	59.1
Changed farm location (near stream)	5.6	3.4	4.5
Sow seeds earlier	22.2	50.0	56.8
Sow seeds twice (if they die)	33.3	35.2	**45.5**
Increased use fertiliser	72.2	87.5	79.5
Increased use pesticide	51.1	52.3	**22.2**
Increased use soil conservation (diversion ditch)	59.1	47.7	38.9
Increased use soil conservation (terrace)	25.0	18.2	11.1
Increased use soil conservation (perennial grass)	73.9	61.4	55.6
Increased use soil conservation (soil cover crop)	26.1	45.5	38.9
Increased use of veterinary care (cows)	48.9	63.6	50.0
Increased use of complementary feed (cows)	43.2	52.3	50.0
Diversify: labour	69.3	59.1	61.1
Diversify: started rearing animals	79.5	61.4	66.7
Diversify: vegetable farming	77.3	68.2	55.6
Diversify: fruit farming	36.4	25.0	**5.6**

In Burundi, households' food security and food quality (during the previous year) increased with increasing wealth groups, with most rich households reporting having both food security and 'good' food quality. This was different in Rwanda, where only 50% of the rich households reported food security and only 11% reported 'good' food quality (Table 4). In general, access to clean water was also greater in Burundi than in Rwanda for the different wealth groups (see Table 4).

Table 4. Households' food security, 'good' food quality and access to clean water (during the previous year) according to wealth groups around Kibira in Burundi (n = 150) and Nyungwe in Rwanda (n = 150). % refers to the % of respondents within each wealth group in that study area.

	Burundi	Rwanda
Food security		
poor	26	11
average	76	16
rich	95	56
'Good' food quality		
poor	58	20
average	82	18
rich	100	11
Clean water access		
poor	63	39
average	97	49
rich	100	78

4. Discussion

4.1. Climatic Changes Observed and Impacts

As we hypothesised, climatic changes were comparably perceived across the Burundi-Rwanda border. The respondents reported not just increased temperatures, the late onset of the long rains, and more dry spells during the long rains but also fewer foggy days and fewer hailstorms. Other studies from Kenya and DR Congo have shown that different socio-cultural groups living in the same mountain region tend to report comparable climatic changes [18,43]. The climatic changes reported in this study agree with farmers' perceptions of climatic changes elsewhere in Rwanda and eastern DR Congo. In Rwanda, farmers in the Nyamagabe district (east of Nyungwe) reported increased uncertainty in the start and amount of rainfall during rainy seasons [17], whereas farmers around the Virunga mountains (north Rwanda) reported the late onset of the rainy season [16]. Farmers in Mt Kahuzi and the Itombwe mountains (in eastern DR Congo), also in the Albertine Rift but to the west of our study area, also reported fewer foggy days and fewer hailstorms [18,19]. In Burundi, farmers' perceptions agree with [20], which showed decreasing trends for both annual and seasonal rainfall in the mountain region of Burundi.

Comparable impacts in the biophysical domain were also reported by farmers in both countries, which are also in agreement with the climate change impacts reported by farmers in other studies in the Albertine Rift region. Increased soil erosion associated with heavy rains was also reported by smallholder farmers living around the Virunga mountains, Mt Kahuzi, and the Itombwe mountains [16,18,19]. This was sometimes linked to the local deforestation of natural forests, as was the case for some of our study respondents in Burundi. In Rwanda, 'local deforestation' was not mentioned as a driver of increased soil erosion as natural forests are only found within well-enforced protected areas (Pers. Obs. 2021). Reduced crop yields and increased disease prevalence were also reported as consequences of changing rainfall patterns in the Virunga mountains, Mt Kahuzi, and the Itombwe mountains [16,18]. Notably, in our study areas, perceived changes in crop yields could be related to nutrient depletion in the soils, due to the continued cultivation of the same fields over time (fallow systems are not currently practised in Burundi or Rwanda). In Rwanda, this could also be related to changes from polyculture to monoculture, as monoculture, promoted by national agricultural programs, has been the norm for over 10 years. In both countries, some respondents also reported reduced cow milk production and an increase in livestock diseases, which was also reported by farmers in the Itombwe mountains [19]. In Burundi, reduced fodder availability due to changing rainfall patterns was linked to reduced milk production in cows, whereas in Rwanda, reduced fodder availability was not mentioned as a driver of reduced milk production, as zero-grazing has been the norm for over 10 years.

4.2. Adaptation Strategies

Some important differences in adaptation strategies were observed between countries, as we also hypothesised. More strategies were reported in Burundi, and more farmers in Burundi were using multiple strategies. This is likely to be driven by greater freedom of choice for experimenting among farmers in Burundi—because of different agricultural policies and lower law enforcement than in Rwanda. Farmers often prioritise their household's food security over income maximisation [27], so implementing multiple adaptation strategies contributes to minimising risks. For example, more farmers in Burundi than in Rwanda changed their farm location or grew new crops. These options are not available in Rwanda, as current agricultural policies, which are highly enforced, limit both crop choice and farm locations [17]. Notably, more farmers in Rwanda were diversifying into vegetable or fruit production. This could be due to both (i) better access to urban markets for those crops in Rwanda and/or (ii) lower government control of such actions (compared to staple crop choice). It should be noted that in the long term, the increased cultivation of water-demanding horticultural crops could threaten farmers' adaptive capacity if future climatic changes reduce water availability [43].

All adaptation strategies mentioned by our study respondents have been reported in other mountain regions in the Albertine Rift. For example, increased irrigation and the increased use of inputs, the increased use of soil conservation techniques, and increased income diversification were also documented by farmers in the Itombwe mountains [19]. Around Mt Kahuzi, growing new crops or crop varieties, cultivating larger farms (to compensate for lower yields), rearing animals, or complementing farming with other off-farm activities were also mentioned [18]. Changing planting dates, soil conservation practices, irrigation, and agroforestry were mentioned by farmers in the Rwenzori Mountains [15]. Cultivating larger farms (to compensate for lower yields) or agroforestry were not mentioned in either Burundi or Rwanda, due to high population density and land scarcity.

4.3. Wealth Effects on Adaptation and Food Security

We also hypothesised that richer households would be using a larger number of adaptation strategies and would have higher food security. We found that this was clearly the case in Burundi, where fewer poor farmers used improved seeds, irrigation, and pesticides or diversified into animal rearing or vegetable farming, and where food security and food quality (during the previous year) increased with increasing wealth. In Rwanda, wealth effects were less conspicuous, particularly for food security, as only 50% of the rich households studied in this country reported food security, and only 11% reported having 'good' food quality. Previous work in Rwanda highlighted that agricultural intensification policies appear to be exacerbating food insecurity among rural farmers. Reference [25] showed that households living in areas of higher CIP intensity were more likely to run out of food earlier than they were ten years ago. Reference [27] reported that 27% of the poor and 13% of the rich farmers they interviewed suffered from food scarcity—a percentage which is even higher in our study area in Rwanda. These authors suggested that it was essential to consider options for easing the requirements of compulsory crop cultivation for households lacking the requisite generic capacities to adapt successfully—something we also recommend.

With regard to food quality, the low response of 'good' food quality among rich households in Rwanda is likely to be driven by a lack of access to their preferred foods. Preferred foods may have always been expensive (for example imported products), but as some participants noted, some traditional food products have become more expensive in the past few years (for example, sweet potatoes, as few farmers in Rwanda cultivate these now). Other studies have documented a change in rural farmers' diets following the CIP in Rwanda [27]. As highlighted by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), food is not just a matter of filling stomachs, it has a cultural dimension [44]. Further work on changing diets related to CIP, and the cultural implications of these changes, is recommended.

4.4. Limitations and Future Research Avenues

Our study approach has some limitations. First, we only studied four villages per country. Although biophysical and socioeconomic differences across the villages within each area studied (Kibira or Nyungwe) are rather limited (for example, market access or the presence of external agents of change), it is possible that by including more villages, other adaptation strategies could be identified. Secondly, we focused on climatic changes as the main challenge to farmers' livelihoods, but other drivers of change such as youth migration to urban centres are likely to act synergistically with climatic change, constraining adaptation options due to, for example, labour constraints. Indeed, climate change, population change, new technologies, globalisation, agricultural policies, and social change are all exerting increasing influence on rural smallholder farmers [27]. Additionally, we have only analysed households' food security and quality, and access to clean water in the previous year. More research on longer timescales and on different aspects of wellbeing, including material, relational, and personal wellbeing dimensions, is recommended. We report a range of on-farm and off-farm adaptation strategies, which could inspire adaptation options in other African mountains. However, we did not investigate their long-term sustainability, such as the potential negative ecological impacts of monocropping (such as reduced soil fertility or an increase in pest outbreaks), something which also requires further investigation.

5. Conclusions

This research has provided a cross-border study on local climate change observations and adaptation strategies used by smallholder farmers in the same mountain region. The results show that farmers in both Burundi and Rwanda report similar climatic changes and impacts on crops, animals, and human health, but that more adaptation strategies are used in Burundi, and more farmers in Burundi are using multiple strategies. This is likely to be driven by greater freedom of choice for experimenting in Burundi because of different agricultural intensification policies and lower law enforcement than in Rwanda. Results show that in both countries, the farmers' wealth affected their adaptation response and their food security. For all wealth groups (poor, average, rich), food security and 'good' food quality was found to be lower in Rwanda than in Burundi. Previous work in Rwanda already emphasised that agricultural intensification policies appear to be exacerbating food insecurity among rural smallholder farmers. The government of Burundi should consider these findings and ensure that their agricultural intensification policies do not exacerbate food insecurity among rural farmers. Given the high spatial variation in climates and soils in mountain regions with complex terrains, high farmer agency might help farmers become more resilient to climate change. This does not imply a lack of technical or external support, but rather, the greater co-production of knowledge among stakeholders, more 'science with society' rather than 'science for society' approaches [45].

Supplementary Materials: The following supporting information (questionnaire used) can be downloaded at: https://www.mdpi.com/article/10.3390/10.3390/land12020329/s1.

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Article

Climate Change and Natural Resource Scarcity: A Literature Review on Dry Farming

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Abstract: The agricultural sector is facing the challenge of climate change, which is increasing difficulties to the activity and the economic sustainability of the primary sector, also affecting farmers' revenues. There is a growing need to support policy makers' decisions and help them develop cross-sectional strategies to support farmers. To this aim and to collect useful information for policy makers and stakeholders for the development of efficient strategies for the management of dryland farming, the paper examines how this issue has been analysed in the literature. A mixed method, based on a systematic literature review and a bibliometric analysis of 79 Scopus documents using VOSviewer software, was applied. Major results highlight the need to implement participatory policy interventions so as to include farmers. It was possible to summarise the main adaptive and technical interventions implemented by farmers. The results indicated the importance of the concept of the resilience of territories and the need to analyse agricultural systems by considering their multifunctionality. The innovativeness of this study relies on its relationships with several policy aspects and not only with purely technical and agronomical features, analysing thus the issue from the under-investigated perspective of the global challenge, contributing to filling this literature gap.

Keywords: climate change; natural resource scarcity; dry farming; dryland farming water scarcity

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1. Introduction

Many authors have highlighted the key role agriculture plays in the sustainable development of a country [1,2] as well as for the development of rural areas, the preservation of biodiversity, economic growth, and food security [2–4].

In recent years, the agricultural sector has faced the challenge of climate change, which is causing an increase in the severity and frequency of extreme weather events and natural disasters [5,6]. Climate change and the agricultural sector have a two-way relationship. More specifically, the agricultural sector is compromised by the effects of climate change, such as the increase in global temperatures and changing precipitation levels and patterns [7]. On the other hand, agricultural activity negatively impacts climate change, e.g., by increasing greenhouse gas emissions [8]. This generates a vicious loop that increases the difficulties of activities in the primary sector and emphasises the need to find new ways to safeguard the entire sector [9]. Moreover, by affecting agricultural yields, climate change also affects farmers' revenues (increasing income volatility) and the economic sustainability of the whole sector. Therefore, it is important to structure and implement adequate and responsive strategies involving either risk management tools or agronomical practices [10]. Moreover, it becomes necessary to stimulate the application of innovative programmes optimising the use of scarce natural resources [11].

According to previous studies [12,13], the greatest impact of climate change will occur in global arid and semi-arid regions. It is crucial to consider this issue because arid and semi-arid ecosystems occupy more than 3 billion hectares and are home to 2.5 billion people [14]. Consequently, the irrigated land available for agricultural production could decrease because of severe water scarcity and the limited availability of new land [13,15].

Because of climate change, natural resources are becoming increasingly scarce, as their rate of regeneration is higher than their rate of consumption. This is particularly noticeable for water. In fact, one of climate change's impacts is the reduction of the occurrence of precipitation, and when it occurs, it happens with very high intensity and time concentration [16]. To cope with this issue, agriculture requires the development of new techniques and management practices [17], such as so-called dryland farming or dry farming [18], a production without irrigation in dry seasons, especially in regions receiving a maximum of 50 cm of rainfall in a year [19]. Surprisingly, drylands are also common in developed countries, characterised by an increased risk of desertification [20]. For example, thirteen European countries have declared to be affected by desertification [20]. For this reason, several European institutions are dealing with desertification issues—e.g., the European Parliament and Council introduced some measures to promote the efficient use of water in agriculture in the Common Agricultural Policy (Re. UE 1305/2013; e.g., by recycling and re-using water resources) [21]. From the literature [22,23], it emerges that Southern Europe is at a higher level of desertification risk than the whole European area, and new strategies are being implemented to cope with water scarcity, such as the use of cover crops to help conserve water in the soil. Moreover, climate change is impacting the agricultural sector by changing cultivation patterns, which also influences international trade, exposing farmers to greater economic losses [24].

All this highlights the weaknesses of the agricultural sector, which is notoriously one of the riskiest production activities because its results are heavily affected by natural conditions such as precipitation. Nowadays, this riskiness is emphasised by the need for sustainable use of natural and scarce resources and has increased because of the growing deterioration of soil fertility, the loss of some important ecosystem services (including biodiversity and wild foods), and the threat of increased climate variability. For these reasons, there is a growing focus on strategies enabling farmers to adapt to current challenges [25,26], especially in arid and semi-arid areas [27]. However, the literature appears to be fragmented and focused only on certain geographic territories, not considering that an increasing area will become arid over time [28].

In recognition of this scenario, the aim of this study is to collect useful information for policy makers and stakeholders who have to develop efficient strategies for the management of dryland farming. The goal of this paper is achieved through the implementation of a systematic literature review on Scopus, one of the major search engines. Synthesising the aspects analysed in various fields allows a representation of reality, giving attention to the needs and risks of the sector to outline and structure specific new policies.

In particular, after an analysis of the current state of the literature from main bibliographic databases such as Scopus, a bibliometric review was implemented. In this case, VOSviewer software was chosen, so the research is based on an objective and replicable analysis. Researchers have already used this software extensively for the analysis of several complex problems; in fact, searching "VOSviewer" on Scopus gives more than 3000 results. On the other hand, the application of bibliometric reviews and the use of this software appear to be poorly implemented in this area of research. The strengths of the VOSviewer software are the easy management of a large number of articles and the ease of clustering the results derived from the search engines in small groups, allowing an intuitive and better synthesis of the results from the literature review.

To the best of our knowledge, various authors have investigated the mentioned issue in different fields of research [2,29,30], but studies focusing on policy implementation are lacking. Therefore, this paper is intended to fill the literature gap—most of the studies on this topic are almost technical. The innovation of this study is linked to advice for policymakers, including economic and financial aspects, about the main needs resulting from climate change and has already been highlighted by researchers of other disciplines. The structure of the paper is as follows: the methodology is described in Section 2, followed by Section 3, in which the results are presented. Sections 4 and 5 are dedicated to the results' discussion and concluding remarks, respectively.

2. Materials and Methods

The study was carried out using a mixed approach based on a systematic literature review followed by bibliometric analysis. In particular, to develop a replicable and objective analysis of the study, a keyword search was deployed on Scopus, while the VOSviewer software was used to implement the bibliometric analysis. Hence, a query was defined with the operator "TITLE-ABS-KEY". The main keywords used in the search were "dryland farming" or "dry farming" and "climate change".

The Scopus database was chosen for several reasons, the main ones concerning the attention given to the peer-review procedure and the accessibility of key information and bibliographic data about publications [31]. In addition, compared to other search engines, it appears to have a larger time coverage that allows for the inclusion of citation analysis and study evolution [32,33]. Moreover, the ease of use is greater than other search engines. In fact, it is possible to export data directly into a form acceptable by many types of software dedicated to bibliometric analysis [31]. To examine how the researchers analysed the phenomenon over time, all available years were included. For this reason, no inclusion or exclusion criteria were applied regarding the period. Moreover, considering that the study is intended to guide policy choices regarding the management of this multidisciplinary topic, no subject areas were excluded. Finally, only open-access articles in the English language published in journals were considered, increasing the opportunity for replication of the study by all those interested in the topic. In conclusion, 79 papers were found to be suitable for the analysis. The paper selection process is shown in Figure 1.

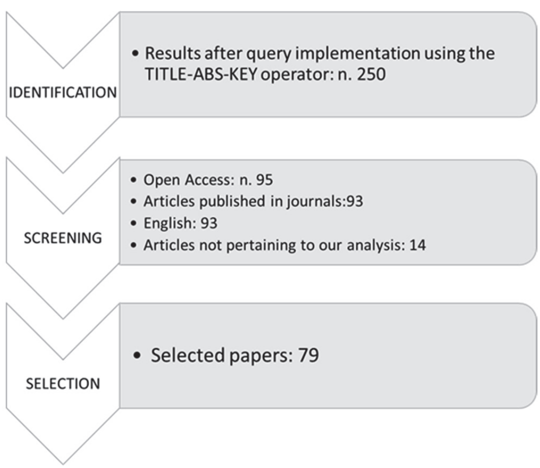

Figure 1. Flow chart of the articles' selection process. Source: our elaboration.

A bibliometric analysis was performed using VOSviewer software, a useful tool to map and graphically represent the relational structure of documents sourced from various search engines. The software identifies clusters of documents according to their correlation degree, so every paper is assigned to a specific cluster, allowing the identification of the main themes considered by the literature. Each cluster has a specific colour, giving a visual identification of relationships between papers. This allows an immediate representation of state of the art, even in the presence of a high number of publications.

3. Results

First, the distribution of scientific articles over time was analysed, and the results are shown in Figure 2.

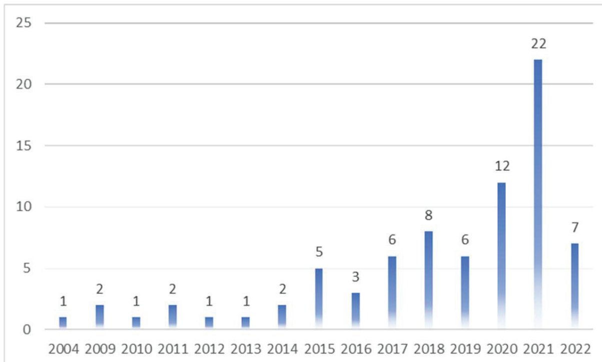

Figure 2. Distribution of the papers over time. Source: our elaboration.

Analysis results show that the selected papers were published between 2004 and 2022; the current year (2022) was included in this study because a large number of papers were congruent with this analysis. On the other hand, an important publication gap emerged from 2004 to 2009. Moreover, Figure 2 shows an increasing trend. Specifically, from 2004 to 2016, the considered topic was discussed in one or two papers annually, with a maximum of five papers published in 2015. However, since 2017, the minimum number of papers published annually has never fallen below six papers. These results highlight the relevance that this issue is receiving in literature, also driven by the many policy documents that put environmental issues at the top of their policy agenda.

Separately analysing research trends related to climate change and dryland farming on the Scopus search engine shows some interesting aspects. As far as climate change, before 2006, there was limited interest in this issue. However, interest increased in relation to an emerging and positive trend of research (Figure 3A). With respect to dryland farming, papers on this topic show an increasing trend, starting from 2015 (Figure 3B) (a possible explanation is the 2030 Agenda signed in 2015).

Then, the analysis was focused on the main journals in which at least two papers were published (Table 1), while the complete list of these journals is provided in Table A1 of the Appendix.

The journals that include the largest number of publications are Climate Change and Sustainability (Switzerland). The variety of topics covered by other journals pushes attention to the multidisciplinary nature of the topic. In fact, other issues largely addressed by those journals are, for example, sustainability, environmental management, risk management and engineering.

Moving on, the analysis was focused on the relationships between the most widely used keywords in the papers. This was conducted to better explore the links between the keywords, thus providing a greater understanding of the state of the art. The lowest allowable number of keyword occurrences was fixed at five, so groups were shaped by considering the keywords appearing together at least five times. Figure 4 shows the most commonly occurring keywords: "climate change", "dryland farming", and "climate effect" or "crop yield"; less common keywords include "irrigation", "desertification", "adaptive management", or "vulnerability".

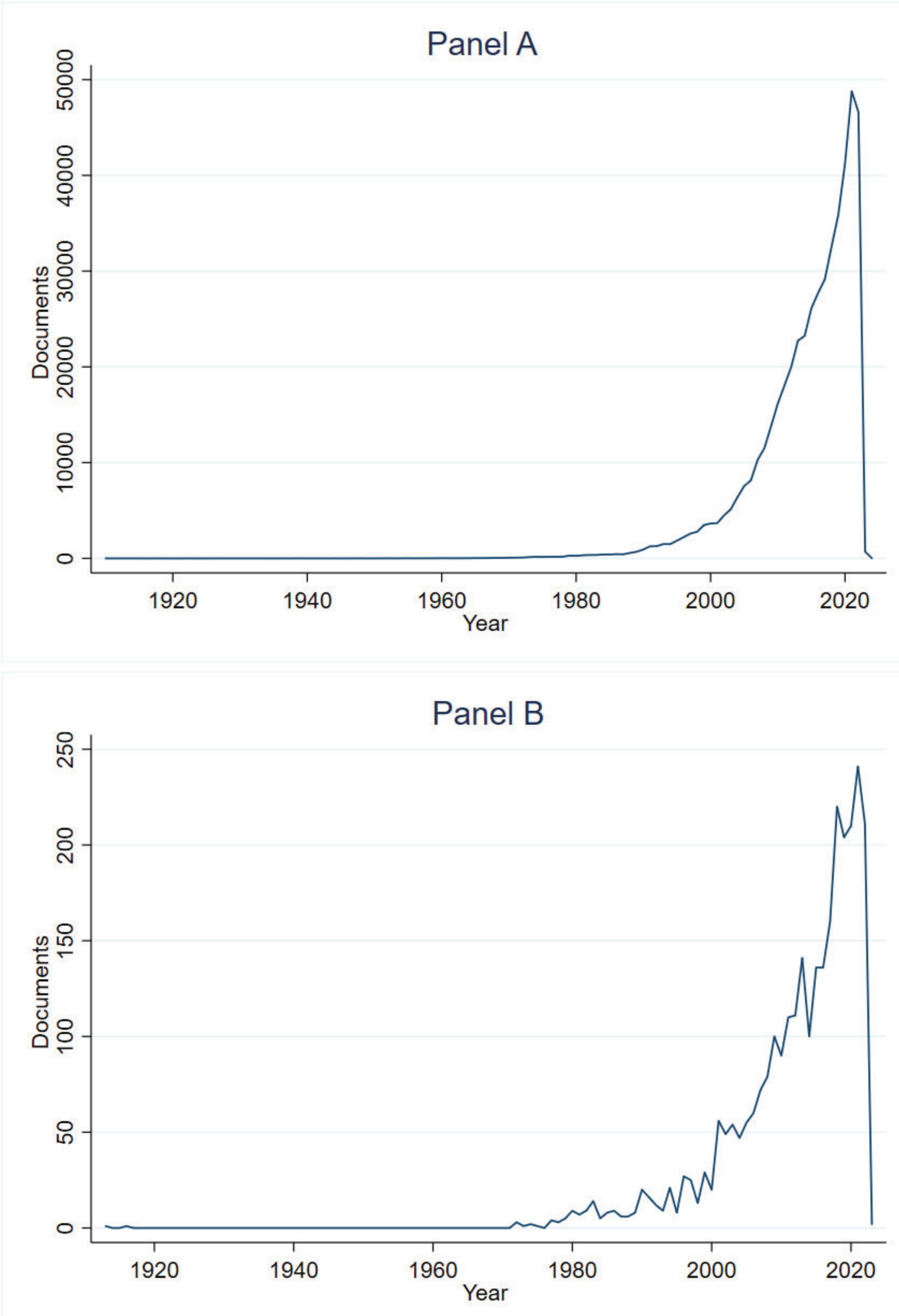

Figure 3. Trend in research about "climate change" (**A**) and "dry farming" or "dryland farming" (**B**). Source: Scopus results.

Table 1. Major journals publishing studies on this topic.

Journal	Number of Papers
Climatic Change	6
Sustainability (Switzerland)	6
Nature Communications	4
Agricultural Systems	3
Ecology and Society	3
Environmental Research Letters	3
Land Use Policy	3
Agriculture, Ecosystems and Environment	2
Current Opinion in Environmental Sustainability	2
International Journal of Water Resources Development	2
Journal of Ecology	2
Land Degradation and Development	2
Science of the Total Environment	2
Water (Switzerland)	2

Source: our elaboration.

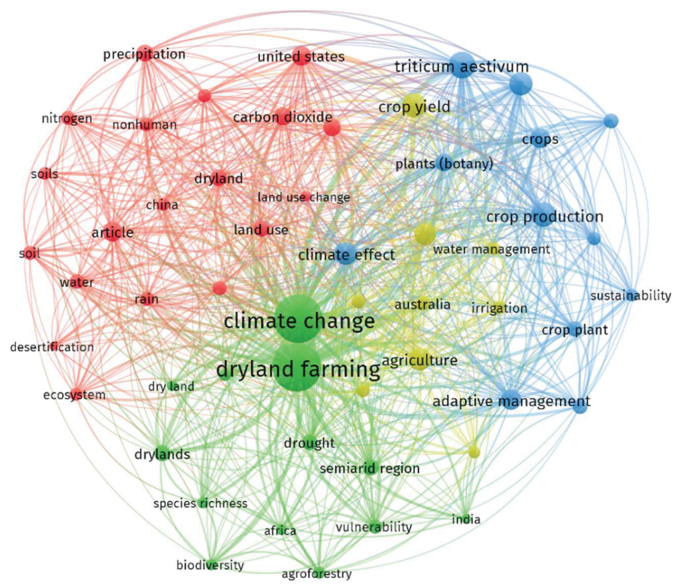

Figure 4. Keyword Network Mapping. Source: VOSviewer elaboration.

3.1. VOSviewer Analysis

The graphic result of the VOSviewer software is shown in Figure 5. More specifically, this analysis divided the search field into five clusters.

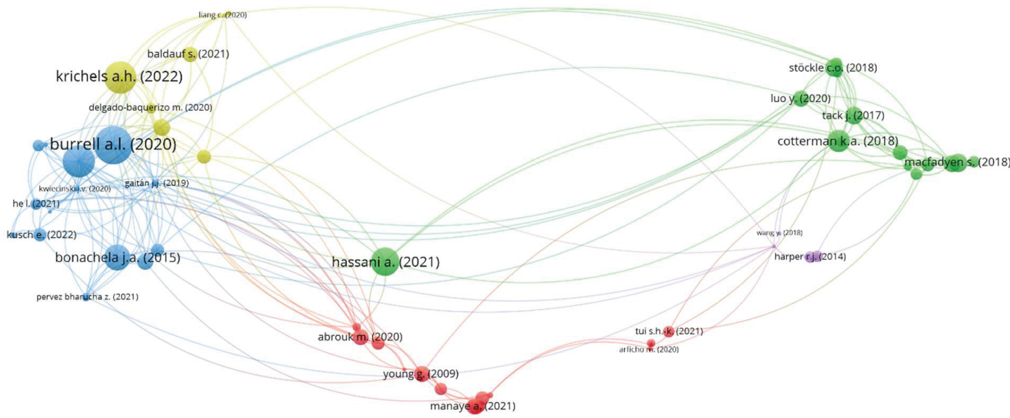

Figure 5. Results of the VOS analysis. Source: VOSviewer elaboration.

Figure 5 shows that the clusters are very distinct from each other, highlighting different views of the issue. Therefore, several aspects will be taken into consideration. Descriptive statistics for each cluster are reported in Table 2, while bibliographic data for each paper are given in the Appendix (Table A2).

Table 2. Cluster descriptive statistics.

	Number of Papers	Total Citations	Total Normalised Citations	Total Citations/ Number of Articles
Red Cluster	21	361	99.804	17.19
Green Cluster	16	447	168.262	27.93
Blue Cluster	16	439	156.207	27.44
Yellow Cluster	9	88	41.134	9.77
Purple Cluster	6	178	3.321	26.67

The Red cluster includes the largest number of items (21), followed by the Green and Blue clusters, both of which include 16 documents. More specifically, the Green cluster has the highest number of total citations (No. 447), and it is the most relevant when considering the ratio of total citations over number of articles.

The different clusters can be summarised as follows:

- The Red cluster, titled “Farmer inclusion and policy interventions”;
- The Green cluster, titled “Potential adaptations to climate change”;
- The Blue cluster, titled “The resilience of arid areas”;
- The Yellow cluster, titled “A variety of indices”;
- The Purple cluster, titled “The multifunctionality of agricultural systems”.

3.1.1. Red Cluster: Farmer Inclusion and Policy Interventions

The Red cluster includes the largest number of papers (21). Specifically, only one paper had not a specific area of study. The remaining twenty were focalised as follows: fourteen papers analysed data on the African continent, four papers were focused on the Asian continent, and the European and American continents were analysed by one paper. This divergence is due to the fact that climate change is one of the major threats affecting food production and the delivery of products and services, especially for developing countries [34].

Bibliometric analysis shows that the paper with the most normalised citations was written by Abrouk et al. [35], analysing the fonio genomic resources, which is the first step toward exploiting the potential of this cereal crop for agriculture in poor environments. Indeed, white fonio is a native West African millet species with characteristics that make it a strategic crop for agriculture in marginal environments [36,37]. Abrouk et al. [35] reveal the key characteristics that make this cereal suitable for arid and semi-arid soils, such as drought resistance and adaptation to nutrient-poor soils, including sandy soils [38].

The importance placed on projects and policy intervention emerges in this cluster [39–41]. Specifically, it is clear from various papers [16,25,42] that the inclusion of farmers is a necessary strategy to address new spatial and environmental challenges and to have timely and lasting results. For example, the 'Farmer-Managed Natural Regeneration' approach, which aims to restore and reforest arable land by working together with farmers, was analysed [43]. In this strategy, groups of the most dynamic farmers in each community have been judged essential for the mobilisation of other community members to learn and experiment [25]. The first result of this approach is a set of psychosocial benefits, such as joy and peacefulness, resulting from the increased beauty and comfort of the greener landscape; increased confidence and experience in leadership for the stakeholders that took part in the groups; improved attitudes toward environmental management and increased optimism for the future of their farms and communities [25].

The projects that have been taken up in these clusters, therefore, promote stakeholder inclusiveness in the area of interest, improved livelihoods, the development of resilient and productive ecosystems, and the development of governance systems that support farmers [39,44].

The literature [25,42,45,46] shows the importance of agroforestry, which is also emphasised in many National Adaptation Programmes of Action (NAPA). Reintroducing trees and shrubs has many benefits: (a) to improve soil nutrients [47]; (b) to increase water infiltration into the soil; (c) to reduce soil evapotranspiration and reduce soil temperature; (d) to increase wildlife diversity, including animal, bird and insect species [48]; (e) to protect the livelihoods of farming households [49]; (f) to diversify income to woody and non-woody tree products [50]; and (g) to improve household resilience to drought or pests [51].

Another aspect emerging from the literature review concerns the techniques that farmers implement to adapt to climate change [27]. Indeed, new water management techniques have been developed to restore soil moisture (referred to as green water), water collection through storage structures (referred to as blue water) [52], new anti-erosion techniques, and mulching [25].

In conclusion, dryland agriculture is a complex and vulnerable system composed of crops (cereals), vegetables, livestock, and trees. Therefore, managing risk and productivity through the adoption of resilient technologies and sustainable intensification is critical to securing income and improving livelihoods in these vulnerable regions [16].

3.1.2. Green Cluster: Potential Adaptations to Climate Change

The Green cluster includes 16 papers concerning a common topic: climate change adaptation strategies.

Indeed, with growing worries about climate change's future influence on agricultural production, many scholars [53–55] have used quantitative and qualitative methods to analyse the strategies farmers adopt to respond to new environmental challenges.

Table 3 summarises the interventions that emerged from the literature. It is important to specify that some of these strategies also emerged in the Red cluster but less frequently. In fact, Figure 5 shows a significant relationship between the two clusters, anticipating the overlap of some themes.

Table 3. The adaptation strategies.

The Adaptation Strategies		
Enhancing the Incorporation of Crop Residues into Soil	Careful Selection of the Most Resilient Crops	Flexible Rotations
Attention to Planting Times	Mixed Crops	Choice of Irrigation Timing and Technology
Agroforestry	Insurance of Crops	Diversified Livestock Farms
Risk management tools adoption	Assignment to Institutional Development Programs	Land Lease
Supplementary Irrigation	Use of Technologies: Sensors And Digital Mapping, Remote Sensing, Meteorological Recording Station	Reduction Of Groundwater Withdrawals.
Alteration of Plant Population Density	Stubble Retention	Improved Weed Control

Several types of potential interventions emerge from Table 3. Some of these are more technical, such as the incorporation of crop residues into the soil [56,57], while others have different natures, such as risk management instruments [10,58]. For example, financial tools, such as crop insurance, allow transferring risks to other subjects, helping farmers face the increasing vulnerability of their activity [59]. Some countries are introducing such instruments in their policies supporting the agricultural sector; these tools are accepted by the WTO because they meet the criterion of causing the least distortions [60].

There are also some interventions that appear to be more economic, such as better weed management, while others seem very expensive and structurally impactful, such as switching to a more resilient crop or moving to a long-term vision based on, for example, an agroforestry approach [61].

The high importance given to technology also emerges. The use of technology (e.g., remote sensing or meteorological recording stations) can greatly support farmers' work and limit their level of uncertainty [62,63].

Developing and implementing new strategies to reduce the impacts of climate change requires implementing information generation and sharing. Indeed, given the vulnerability of the studied areas, increased data and data sharing are necessary to assist land managers and policymakers in understanding environmental dynamics [64].

3.1.3. Blue Cluster: The Resilience of Arid Areas

As in the Green cluster, the Blue cluster includes 16 articles. The themes that emerged from this cluster can be summarised as follows: (i) soil analysis in arid and semi-arid areas and (ii) the resilience of arid areas.

As shown in Figure 5, the Blue cluster is very far from the Green cluster. In fact, it contains no papers analysing potential approaches to respond to climate change. On the other hand, the use of technological equipment emerges as an innovative strategy to respond to new challenges [60,65]. However, Figure 5 shows the proximity of the Blue cluster to the Red cluster: A focus on aspects such as inclusion and vulnerability of drylands emerges in both cases [66].

As already anticipated, the literature [67–69] shows the importance of analysing the soil of arid and semi-arid areas. One of the indicators that appear appropriate is soil organic carbon, which is used to monitor soil degradation and desertification processes in arid areas [70].

This cluster points to the need to analyse these areas' soil through quantitative approaches. This is partly because unsustainable land use is considered the main negative factor in the degradation of drylands [71]. On the other hand, soil management analysis is seen as a multidisciplinary challenge that includes social, economic, and political factors [68,70].

Many scholars [72,73] have stressed the need to analyse the resilience of these areas. Starting from the definition of resilience (an area's ability to resist disturbances and maintain overall functioning), this turns out to be a challenge to be analysed by researchers and stakeholders. Resilience has been incorporated within many of the United Nations Sustainable Development Goals, but the recent attention given to this issue brings with it the difficulty of measurement, especially with reference to the territory over time and space [74]. In fact, although several resilience measurements have been proposed (e.g., resilience to disturbance, rate of recovery from disturbance, and robustness), it remains difficult to find a strategy to make them applicable and operational [72,73].

3.1.4. Yellow Cluster: A Variety of Indices

The Yellow cluster highlights a very important thematic in dryland analysis: the variety of indices used in the literature.

Many authors have used or implemented several indices to analyse issues related to the management of current challenges and the implementation of econometric models.

According to Liang et al. [75], some commonly used indices include the Palmer Drought Severity Index, Standardised Precipitation Index, and Standardised Precipitation Evapotranspiration Index.

Other indices analyse the phenological timing and bioclimatic requirements of certain tree species, monitoring soils' physical, chemical, and biological status to manage their sustainability, such as the Thornthwaite moisture index [76].

A growing body of literature appears to be focused on analysing the issue using this wide choice of indices, but the topic remains very controversial. It is important to find data, but the availability and retrieval of data turn out to be difficult in such contiguous areas [75].

On the other hand, the accuracy and reliability of calculating the indices must be contextualised to the areas where the data are collected. In fact, these data might suggest the implementation of strategies that cannot be adopted or are not effective because of non-quantifiable aspects of the problem, such as farmers' tacit knowledge or their readiness to respond to changes [77].

3.1.5. Purple Cluster: The Multifunctionality of Agricultural Systems

The Purple cluster contains the least number of documents (6). As shown in Figure 5, the last cluster has many relationships with the Green cluster. The main synergies are related to the focus on possible strategies to mitigate the effects of climate change on agriculture.

Several authors (such as [78]) have highlighted the need to select crop varieties that are more appropriate to the current environmental situation and are able to withstand difficult conditions. For example, Acharya et al. [79] reported on the cactus pear (Opuntia ficus-indica), a crop famous for its food and medicinal values. This crop has low water requirements and is tolerant to high temperatures, making it an advantageous crop for growing in arid and semi-arid environments [79].

Other strategies that have emerged from the literature include significant useful water-saving adaptations, e.g., improvement of crop varieties, mechanisation of some agricultural steps, improvement of agricultural infrastructure, agricultural subsidy, and development of dry farming technologies [56,80,81]. On the other hand, the analysis revealed various actions that can increase the efficiency of precipitation management, such as responsible fertilisation, alteration in crop rotation, or inclusion of annual forage crops [81,82]

Two interconnected themes also emerge from the Purple cluster that are very important to the issue: the management of agricultural systems and the management of common goods.

According to Wang et al. [82], agricultural systems are defined as multifunctional ecosystems. Their function is not only limited to food production but also to the provision of ecosystem services. In addition, various natural resource management issues require interdisciplinary knowledge.

This view of the topic relates to another paper in this cluster written by Loch and Gregg [81], who analysed the difficult management of common goods, such as water quality. Specifically, public institutions generally invest in two main activities: the first is represented by administering, monitoring, and enforcing current policy provisions, and the second focuses on designing and transitioning existing management agreements or creating new ones.

Hence, this cluster is focused on sustainable, long-term management of agricultural systems, which must be profitable and less impactful on natural resources. This opens the way to a new challenge addressed to policy makers and researchers: Even where the data appear to be fragmented, there is an emerging need to manage ecosystems to make them resilient without overlooking the key characteristic of these areas, which is multifunctionality.

4. Discussion

Results show researchers' increasing focus on issues linking drylands and climate change (Figure 2). In addition, five clusters emerged that divided the current literature into five macro areas.

More specifically, the need to include farmers and develop increasingly participatory policy interventions emerged (Red cluster). Secondly (Green cluster), the more technical papers analysed potential adaptive interventions implemented by farmers and supported by policies. Subsequently (Blue cluster), the literature has emphasised the importance of a relatively new concept: the resilience of territories and the difficulty of finding indices to measure it. At the same time, the Yellow cluster highlighted the presence of a multitude of indices used for the analysis of these issues. Finally, the Purple cluster reported the need to analyse agricultural systems by considering their multifunctionality.

In fact, the analysis revealed a surprising aspect of the management of this issue. When considering drylands as significantly vulnerable areas, the literature suggests using participatory approaches intended to increase the social capital of the area significantly and aiming to construct territorial resilience [52]. In fact, social capital influences farmers' ability to adapt to new threats, and the process is facilitated by the increased availability of information, greater trust in institutions, and facilitated use of resources [44,83,84]. On the other hand, promoting the resilience of areas is necessary to mitigate the effects of climate change and re-evaluate affected areas [72,73].

Indeed, resilience concerns unpredictable events and their impacts, suggesting the necessity of strategies to enhance systems' adaptability and transformability [2]. Climate change as a process is not expected to retreat to the extent that the world will not need to adapt to its effects. Another key factor in fighting climate change's impacts is social capital, as knowing about specific topics in agricultural areas could lead to the implementation of winning strategies. Moreover, resource scarcity limiting the development of the agricultural sector poses the need for new, developing factors, such as those related to resilience and social capital. For example, local development could be enhanced by the increasing sharing of knowledge, implemented thanks to higher levels of social capital. The world cannot continue to face the economic impact of climate change as it has always done. Social capital is the key factor in generating resilience since a territory's adaptive capacity depends on local knowledge, networks, and attitude towards innovation.

Another strategy that appears to be under-adopted is the use of financial tools to transfer risks. In fact, many authors (e.g., [85,86]) have reported that financial insurance for extreme events can be used to face the impacts of climate change and could be an important adaptation strategy. Agricultural risk management is becoming increasingly important, as seen, for example, in the latest European Common Agricultural Policy 2014–2020 (CAP) [87,88]. The Common Agricultural Policy (Reg UE 1305/2013) provides various instruments for risk management (art. 36)—i.e., agricultural insurance (art. 37), mutual funds (art. 38), and the income stabilisation tool (art. 39) [21]. However, the demand for these tools is still low, and integrated policy intervention must be implemented to enhance their adoption [89]. To this end, it is also important to have a large set of data to better structure adequate policies and to give each area a specific instrument to promote local development. From this review, the need to use data and information also emerged: even if it is a difficult challenge and there are many obstacles to overcome, the first step to supporting territories is knowing those territories.

5. Conclusions

In recent years, the impacts of climate change have received significant attention in literature and in many policy documents [42]. More specifically, increasing temperatures and the constantly changing magnitude and frequency of meteorological events are causing growing concerns about new strategies to react to these threats, which will be more impactful in the growing arid and semi-arid areas [12,13].

To support the policy makers' decision making and help develop cross-sectional strategies to support farmers, this paper is intended to examine how this issue has been analysed in the literature and to highlight the opportunities and bottlenecks on which interventions now needed can be based. The outcome was achieved by applying a mixed method based on a systematic literature review and subsequent bibliometric analysis using VOSviewer software.

The literature review revealed the relevance of the analysed issue. Preliminary results showed 250 articles related to dryland farming and climate change. After the screening, only 79 articles were selected to be included in this review. Of these works, more than 80% were published after 2015, when Agenda 2030 was signed, implying an increase in researchers' efforts to study these phenomena to find solutions to climate change and giving major attention to the role of the agricultural sector.

The review also exposed the multidisciplinary nature of the investigated issue, emerging from the cluster division of the works. Papers were allocated in five clusters, sometimes overlapping. The cluster of greater relevance concerns farmer inclusion and policy interventions (21 papers out of 79), followed by the potential adaptations to climate change and the resilience of arid areas (each containing 16 works). The literature focused on the agricultural sector's weaknesses to define a common policy strategy.

In fact, this issue is even more accentuated in the primary sector, which shows a close connection and dependence between the environmental threats and the economic stability of the whole sector [7]. Indeed, yield productivity increases and evolves into the augmented volatility of farmers' revenue. To face these issues in the current scenario, focused mainly on practical solutions, it is also necessary to integrate several instruments (e.g., of agronomic and financial natures), thanks to the implementation of adequate policies.

6. Policy Implications

As highlighted in the Introduction section, this study aims to fill the literature gap about policy implementation since most of the previous studies have a technical approach rather than a policy one. As it emerged from the results' discussion, there is an increasing need to develop and adopt participatory policy interventions. This is particularly true for the social capital that was indicated as one of the fundamental elements of improving the effectiveness and reducing the risk of failure of the policies. To this aim, a crucial role will be played by the social and human capital as well as by generational renewal. Therefore, training instruments and access to information for farmers will represent elements of crucial importance that could help to build and boost social capital and trust in institutions, facilitating the resources use.

Moreover, a crucial role in guiding farmers through risk management and facing climate change strategies will be played by institutions. Specifically, they could monitor the changes in drought levels and promote coping, as well as implement multidisciplinary strategies by integrating different actors.

A further important contribution that institutions may provide is also represented by investments in innovations. In fact, for some farmers, especially the smallest ones, it is hard to invest in the specific tools and technologies needed to face climate change. Therefore, policies should promote technological renewal and help the farmers to adopt innovations by providing financial support and fostering knowledge sharing.

It is also crucial to analyse agricultural systems, considering their multifunctionality, to build up territorial resilience and sustainable development. In fact, when income from production decreases, activities connected to the rural reality (for example, agritourism) play a relevant role. In this direction, adopting local crop varieties could be a winning strategy to foster agricultural sustainability in marginal areas based on their ability to exploit limited resources and cope with extreme weather conditions.

Another way to address the difficulties caused by climate change and by territories' weaknesses is represented by financial tools to transfer risks on the market. Even if they are largely under-adopted, they could represent a relevant chance to promote the economic sustainability of farmers' activities. Policies should promote their use not only by providing financial support (fundamental for their desirability) but also by facilitating the availability of such subsidies. To enhance this sector (and many others), it is also important to facilitate access to information that can help farmers and insurers gain a realistic idea of activities' riskiness.

Finally, access to data would help farmers implement precision agriculture, another possible strategy to maintain agricultural activities in marginal areas facing adverse climate conditions. Furthermore, access to meteorological data is essential to plan an efficient cropping calendar and help farmers determine the right climatic conditions for crop growing.

7. Limitations and Directions for Future Research

This paragraph contains a discussion of some limitations of the present study, followed by some suggestions for possible future research.

The idea of this paper was to analyse the issue of climate change and dryland farming from the perspective of a global challenge. The main limit of the study is that other scholars might have chosen other keywords on which to base their investigation of the current situation in this field. However, in this case, the goal was to highlight future paths on which to base cross-sectional effective and efficient policy interventions. Due to the literature gap and the increasing attention given to the issue by institutional policies, future researchers may analyse the effects of climate change on the agricultural and agricultural risk-management sectors, particularly in developed countries. Moreover, research on separate topics could be carried out to catch up on other relevant aspects.

It is also noteworthy that the issues of drought and desertification are somewhat different in each geographical area. Therefore, evaluating how the problem has been analysed so far in various countries could be of interest. This would also be interesting considering countries' strengths, as they have different types of power to face climate change's effects. Poorer territories have fewer economic resources to invest in providing policy instruments for farmers and, often, less human capital to implement innovative strategies. For this reason, broad studies (such as the present one) represent elements of interest that allow knowledge spread among territories.

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Data Availability Statement: Informed consent was obtained from all subjects involved in the study.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Major journals publishing studies on this topic.

Journal	Number of Papers
Climatic Change	6
Sustainability (Switzerland)	6
Nature Communications	4
Agricultural Systems	3
Ecology and Society	3
Environmental Research Letters	3
Land Use Policy	3
Agriculture, Ecosystems and Environment	2
Current Opinion in Environmental Sustainability	2
International Journal of Water Resources Development	2
Journal of Ecology	2
Land Degradation and Development	2
Science of the Total Environment	2
Water (Switzerland)	2
Arid Land Research and Management	1
Biogeochemistry	1
Biology Letters	1
Carbon Balance and Management	1
Climate and Development	1
Diversity	1
Ecological Indicators	1
Ecosystems	1
Environmental Management	1
European Journal of Soil Science	1
Field Crops Research	1
Forests	1
Forests Trees and Livelihoods	1
Frontiers in Ecology and The Environment	1
Gcb Bioenergy	1
Geoforum	1
Heliyon	1
Ids Bulletin	1
International Journal of Agricultural Sustainability	1
International Journal of Environmental Research and Public Health	1
Journal of Applied Ecology	1
Journal of Environmental Management	1
New Phytologist	1
Njas - Wageningen Journal of Life Sciences	1
Remote Sensing of Environment	1
Science	1
Soil Biology and Biochemistry	1
Theoretical and Applied Climatology	1
Water Sa	1

Table A2. Papers considered in the study.

VOS Label	Authors	Title	Journal	Year	Cluster	Citations	Norm. Citations
Abrouk M. (2020)	Abrouk M.; Ahmed H.I.; Cubry P.; Šimoníková D.; Cauet S.; Pailles Y.; Bettgenhaeuser J.; Gapa L.; Scarcelli N.; Couderc M.; Zekraoui L.; Kathiresan N.; Čížková J.; Hřibová E.; Doležel J.; Arribat S.; Bergès H.; Wieringa J.J.; Gueye M.; Kane N.A.; Leclerc C.; Causse S.; Vancoppenolle S.; Billot C.; Wicker T.; Vigouroux Y.; Barnaud A.; Krattinger S.G.	Fonio Millet Genome Unlocks African Orphan Crop Diversity For Agriculture In A Changing Climate	Nature Communications, 11(1)	2020	Red	26	15.089
Young G. (2009)	Young G.; Zavala H.; Wandel J.; Smit B.; Salas S.; Jimenez E.; Fiebig M.; Espinoza R.; Diaz H.; Cepeda J.	Vulnerability And Adaptation In A Dryland Community Of The Elqui Valley, Chile	Climatic Change, 98(1–2), 245–276	2009	Red	65	14.943
Manaye A. (2021)	Manaye A.; Tesfamariam B.; Tesfaye M.; Worku A.; Gufi Y.	Tree Diversity And Carbon Stocks In Agroforestry Systems In Northern Ethiopia	Carbon Balance And Management, 16(1)	2021	Red	8	13.521
Villamor G.B. (2016)	Villamor G.B.; Badmos B.K.	Grazing Game: A Learning Tool For Adaptive Management In Response To Climate Variability In Semiarid Areas Of Ghana	Ecology And Society, 21(1)	2016	Red	28	12.174
Endale Y. (2017)	Endale Y.; Derero A.; Argaw M.; Muthuri C.	Farmland Tree Species Diversity And Spatial Distribution Pattern In Semi-Arid East Shewa, Ethiopia	Forests Trees And Livelihoods, 26(3), 199–214	2017	Red	32	12.075
Moreno-Jiménez E. (2022)	Moreno-Jiménez E.; Orgiazzi A.; Jones A.; Saiz H.; Aceña-Heras S.; Plaza C.	Aridity And Geochemical Drivers Of Soil Micronutrient And Contaminant Availability In European Drylands	European Journal Of Soil Science, 73(1)	2022	Red	1	11.667
Kattumuri R. (2017)	Kattumuri R.; Ravindranath D.; Esteves T.	Local Adaptation Strategies In Semi-Arid Regions: Study Of Two Villages In Karnataka, India	Climate And Development, 9(1), 36–49	2017	Red	27	10.189
Tui S.H.-K. (2021)	Tui S.H.-K.; Descheemaeker K.; Valdivia R.O.; Masikati P.; Sisito G.; Moyo E.N.; Crespo O.; Ruane A.C.; Rosenzweig C.	Climate Change Impacts And Adaptation For Dryland Farming Systems In Zimbabwe: A Stakeholder-Driven Integrated Multi-Model Assessment	Climatic Change, 168(1–2)	2021	Red	6	10.141
Scoones I. (2004)	Scoones I.	Climate Change And The Challenge Of Non-Equilibrium Thinking	Ids Bulletin, 35(3), 114–119	2004	Red	29	1
Weston P. (2015)	Weston P.; Hong R.; Kaboré C.; Kull C.A.	Farmer-Managed Natural Regeneration Enhances Rural Livelihoods In Dryland West Africa	Environmental Management, 55(6), 1402–1417	2015	Red	50	0.9363

Table A2. *Cont.*

VOS Label	Authors	Title	Journal	Year	Cluster	Citations	Norm. Citations
Antwi-Agyei P. (2015)	Antwi-Agyei P.; Dougill A.J.; Stringer L.C.	Impacts Of Land Tenure Arrangements On The Adaptive Capacity Of Marginalized Groups: The Case Of Ghana's Ejura Sekyedumase And Bongo Districts	Land Use Policy, 49, 203–212	2015	Red	41	0.7678
Sun Y. (2021)	Sun Y.; Sun Y.; Yao S.; Akram M.A.; Hu W.; Dong L.; Li H.; Wei M.; Gong H.; Xie S.; Aqeel M.; Ran J.; Degen A.A.; Guo Q.; Deng J.	Impact Of Climate Change On Plant Species Richness Across Drylands In China: From Past To Present And Into The Future	Ecological Indicators, 132	2021	Red	4	0.6761
Recha J.W. (2016)	Recha J.W.; Mati B.M.; Nyasimi M.; Kimeli P.K.; Kinyangi J.M.; Radeny M.	Changing Rainfall Patterns And Farmers' Adaptation Through Soil Water Management Practices In Semi-Arid Eastern Kenya	Arid Land Research And Management, 30(3), 229–238	2016	Red	15	0.6522
Kalame F.B. (2011)	Kalame F.B.; Luukkanen O.; Kanninen M.	Making The National Adaptation Programme Of Action (Napa) More Responsive To The Livelihood Needs Of Tree Planting Farmers, Drawing On Previous Experience In Dryland Sudan	Forests, 2(4), 948–960	2011	Red	5	0.4762
Ndhleve S. (2017)	Ndhleve S.; Nakin M.D.V.; Longo-Mbenza B.	Impacts Of Supplemental Irrigation As A Climate Change Adaptation Strategy For Maize Production: A Case Of The Eastern Cape Province Of South Africa	Water Sa, 43(2), 222–228	2017	Red	12	0.4528
Galvin K.A. (2021)	Galvin K.A.	Transformational Adaptation In Drylands	Current Opinion In Environmental Sustainability, 50, 64–71	2021	Red	2	0.338
Arficho M. (2020)	Arficho M.; Thiel A.	Does Land-Use Policy Moderate Impacts Of Climate Anomalies On Lulc Change In Dry-Lands? An Empirical Enquiry Into Drivers And Moderators Of Lulc Change In Southern Ethiopia	Sustainability (Switzerland), 12(15)	2020	Red	4	0.2321
Mulligan M. (2015)	Mulligan M.	Climate Change And Food-Water Supply From Africa's Drylands: Local Impacts And Teleconnections Through Global Commodity Flows	International Journal Of Water Resources Development, 31(3), 450–460	2015	Red	5	0.0936

Table A2. *Cont.*

VOS Label	Authors	Title	Journal	Year	Cluster	Citations	Norm. Citations
Gebru K.M. (2020)	Gebru K.M.; Woldearegay K.; Van Steenbergen F.; Beyene A.; Vera L.F.; Gebreegziabher K.T.; Alemayhu T.	Adoption Of Road Water Harvesting Practices And Their Impacts: Evidence From A Semi-Arid Region Of Ethiopia	Sustainability (Switzerland), 12(21), 1–25	2020	Red	1	0.058
Chanza N. (2022)	Chanza N.; Musakwa W.	Ecological And Hydrological Indicators Of Climate Change Observed By Dryland Communities Of Malipati In Chiredzi, Zimbabwe	Diversity, 14(7)	2022	Red	0	0
Samuel J. (2022)	Samuel J.; Rao C.A.R.; Raju B.M.K.; Reddy A.A.; Pushpanjali, Reddy A.G.K.; Kumar R.N.; Osman M.; Singh V.K.; Prasad J.V.N.S.	Assessing The Impact Of Climate Resilient Technologies In Minimizing Drought Impacts On Farm Incomes In Drylands	Sustainability (Switzerland), 14(1)	2022	Red	0	0
Hassani A. (2021)	Hassani A.; Azapagic A.; Shokri N.	Global Predictions Of Primary Soil Salinization Under Changing Climate In The 21st Century	Nature Communications, 12(1)	2021	Green	18	30.423
Cotterman K.A. (2018)	Cotterman K.A.; Kendall A.D.; Basso B.; Hyndman D.W.	Groundwater Depletion And Climate Change: Future Prospects Of Crop Production In The Central High Plains Aquifer	Climatic Change, 146(1–2), 187–200	2018	Green	43	22.114
Macfadyen S. (2018)	Macfadyen S.; Mcdonald G.; Hill M.P.	From Species Distributions To Climate Change Adaptation: Knowledge Gaps In Managing Invertebrate Pests In Broad-Acre Grain Crops	Agriculture, Ecosystems And Environment, 253, 208–219	2018	Green	34	17.486
Tack J. (2017)	Tack J.; Barkley A.; Hendricks N.	Irrigation Offsets Wheat Yield Reductions From Warming Temperatures	Environmental Research Letters, 12(11)	2017	Green	45	16.981
Stöckle C.O. (2018)	Stöckle C.O.; Higgins S.; Nelson R.; Abatzoglou J.; Huggins D.; Pan W.; Karimi T.; Antle J.; Eigenbrode S.D.; Brooks E.	Evaluating Opportunities For An Increased Role Of Winter Crops As Adaptation To Climate Change In Dryland Cropping Systems Of The U.S. Inland Pacific Northwest	Climatic Change, 146(1–2), 247–261	2018	Green	33	16.971
Thamo T. (2017)	Thamo T.; Addai D.; Pannell D.J.; Robertson M.J.; Thomas D.T.; Young J.M.	Climate Change Impacts And Farm-Level Adaptation: Economic Analysis Of A Mixed Cropping–Livestock System	Agricultural Systems, 150, 99–108	2017	Green	41	15.472
Luo Y. (2020)	Luo Y.; Zhang Z.; Li Z.; Chen Y.; Chen Y.; Zhang L.; Cao J.; Tao F.; Tao F.	Identifying The Spatiotemporal Changes Of Annual Harvesting Areas For Three Staple Crops In China By Integrating Multi-Data Sources	Environmental Research Letters, 15(7)	2020	Green	25	14.509

Table A2. *Cont.*

VOS Label	Authors	Title	Journal	Year	Cluster	Citations	Norm. Citations
Yang C. (2019)	Yang C.; Fraga H.; Van Ieperen W.; Trindade H.; Santos J.A.	Effects Of Climate Change And Adaptation Options On Winter Wheat Yield Under Rainfed Mediterranean Conditions In Southern Portugal	Climatic Change, 154(1–2), 159–178	2019	Green	39	12.857
Ghahramani A. (2016)	Ghahramani A.; Moore A.D.	Impact Of Climate Changes On Existing Crop-Livestock Farming Systems	Agricultural Systems, 146, 142–155	2016	Green	26	11.304
Karimi T. (2021)	Karimi T.; Stöckle C.O.; Higgins S.S.; Nelson R.L.	Impact Of Climate Change On Greenhouse Gas Emissions And Water Balance In A Dryland-Cropping Region With Variable Precipitation	Journal Of Environmental Management, 287	2021	Green	6	10.141
Asseng S. (2013)	Asseng S.; Pannell D.J.	Adapting Dryland Agriculture To Climate Change: Farming Implications And Research And Development Needs In Western Australia	Climatic Change, 118(2), 167–181	2013	Green	53	1
Monjardino M. (2010)	Monjardino M.; Revell D.; Pannell D.J.	The Potential Contribution Of Forage Shrubs To Economic Returns And Environmental Management In Australian Dryland Agricultural Systems	Agricultural Systems, 103(4), 187–197	2010	Green	39	1
Shayanmehr S. (2020)	Shayanmehr S.; Henneberry S.R.; Sabouni M.S.; Foroushani N.S.	Drought, Climate Change, And Dryland Wheat Yield Response: An Econometric Approach	International Journal Of Environmental Research And Public Health, 17(14), 1–18	2020	Green	14	0.8125
Antle J.M. (2018)	Antle J.M.; Zhang H.; Mu J.E.; Abatzoglou J.; Stöckle C.	Methods To Assess Between-System Adaptations To Climate Change: Dryland Wheat Systems In The Pacific Northwest United States	Agriculture, Ecosystems And Environment, 253, 195–207	2018	Green	15	0.7714
Lawrence P.G. (2018)	Lawrence P.G.; Maxwell B.D.; Rew L.J.; Ellis C.; Bekkerman A.	Vulnerability Of Dryland Agricultural Regimes To Economic And Climatic Change	Ecology And Society, 23(1)	2018	Green	13	0.6686
Zhang H. (2018)	Zhang H.; Mu J.E.; Mccarl B.A.	Adaptation To Climate Change Via Adjustment In Land Leasing: Evidence From Dryland Wheat Farms In The U.S. Pacific Northwest	Land Use Policy, 79, 424–432	2018	Green	3	0.1543

Table A2. *Cont.*

VOS Label	Authors	Title	Journal	Year	Cluster	Citations	Norm. Citations
Burrell A.L. (2020)	Burrell A.L.; Evans J.P.; De Kauwe M.G.	Anthropogenic Climate Change Has Driven Over 5 Million Km2 Of Drylands Towards Desertification	Nature Communications, 11(1)	2020	Blue	77	44.688
Smith W.K. (2019)	Smith W.K.; Dannenberg M.P.; Yan D.; Herrmann S.; Barnes M.L.; Barron-Gafford G.A.; Biederman J.A.; Ferrenberg S.; Fox A.M.; Hudson A.; Knowles J.F.; Macbean N.; Moore D.J.P.; Nagler P.L.; Reed S.C.; Rutherford W.A.; Scott R.L.; Wang X.; Yang J.	Remote Sensing Of Dryland Ecosystem Structure And Function: Progress, Challenges, And Opportunities	Remote Sensing Of Environment, 233	2019	Blue	107	35.275
Bonachela J.A. (2015)	Bonachela J.A.; Pringle R.M.; Sheffer E.; Coverdale T.C.; Guyton J.A.; Caylor K.K.; Levin S.A.; Tarnita C.E.	Termite Mounds Can Increase The Robustness Of Dryland Ecosystems To Climatic Change	Science, 347(6222), 651–655	2015	Blue	147	27.528
Twyman C. (2011)	Twyman C.; Fraser E.D.G.; Stringer L.C.; Quinn C.; Dougill A.J.; Ravera F.; Crane T.A.; Sallu S.M.	Climate Science, Development Practice, And Policy Interactions In Dryland Agroecological Systems	Ecology And Society, 16(3), 19	2011	Blue	16	15.238
Kusch E. (2022)	Kusch E.; Davy R.; Seddon A.W.R.	Vegetation-Memory Effects And Their Association With Vegetation Resilience In Global Drylands	Journal Of Ecology, 110(7), 1561–1574	2022	Blue	1	11.667
Cai L. (2022)	Cai L.; Wang H.; Liu Y.; Fan D.; Li X.	Is Potential Cultivated Land Expanding Or Shrinking In The Dryland Of China? Spatiotemporal Evaluation Based On Remote Sensing And Svm	Land Use Policy, 112	2022	Blue	1	11.667
He L. (2021)	He L.; Li Z.-L.; Wang X.; Xie Y.; Ye J.-S.	Lagged Precipitation Effect On Plant Productivity Is Influenced Collectively By Climate And Edaphic Factors In Drylands	Science Of The Total Environment, 755	2021	Blue	6	10.141
Gaitán J.J. (2014)	Gaitán J.J.; Bran D.; Oliva G.; Maestre F.T.; Aguiar M.R.; Jobbagy E.; Buono G.; Ferrante D.; Nakamatsu V.; Ciari G.; Salomone J.; Massara V.	Plant Species Richness And Shrub Cover Attenuate Drought Effects On Ecosystem Functioning Across Patagonian Rangelands	Biology Letters, 10(10)	2014	Blue	17	1
Pervez Bharucha Z. (2021)	Pervez Bharucha Z.; Attwood S.; Badiger S.; Balamatti A.; Bawden R.; Bentley J.W.; Chander M.; Davies L.; Dixon H.; Dixon J.; D'souza M.; Butler Flora C.; Green M.; Joshi D.; Komarek A.M.; Ruth Mcdermid L.; Mathijs E.; Rola A.C.; Patnaik S.; Pattanayak S.; Pingali P.; Vara Prasad V.P.; Rabbinge R.; Ramanjaneyulu G.V.; Ravindranath N.H.; Sage C.; Saha A.; Salvatore C.; Patnaik Saxena L.; Singh C.; Smith P.; Srinidhi A.; Sugam R.; Thomas R.; Uphoff N.; Pretty J.	The Top 100 Questions For The Sustainable Intensification Of Agriculture In India's Rainfed Drylands	International Journal Of Agricultural Sustainability, 19(2), 106–127	2021	Blue	4	0.6761

Table A2. *Cont.*

VOS Label	Authors	Title	Journal	Year	Cluster	Citations	Norm. Citations
Gaitán J.J. (2019)	Gaitán J.J.; Maestre F.T.; Bran D.E.; Buono G.G.; Dougill A.J.; García Martínez G.; Ferrante D.; Guuroh R.T.; Linstädter A.; Massara V.; Thomas A.D.; Oliva G.E.	Biotic And Abiotic Drivers Of Topsoil Organic Carbon Concentration In Drylands Have Similar Effects At Regional And Global Scales	Ecosystems, 22(7), 1445–1456	2019	Blue	15	0.4945
Browning D.M. (2015)	Browning D.M.; Rango A.; Karl J.W.; Laney C.M.; Vivoni E.R.; Tweedie C.E.	Emerging Technological And Cultural Shifts Advancing Drylands Research And Management	Frontiers In Ecology And The Environment, 13(1), 52–60	2015	Blue	24	0.4494
Kwiecinski J.V. (2020)	Kwiecinski J.V.; Stricker E.; Sinsabaugh R.L.; Collins S.L.	Rainfall Pulses Increased Short-Term Biocrust Chlorophyll But Not Fungal Abundance Or N Availability In A Long-Term Dryland Rainfall Manipulation Experiment	Soil Biology And Biochemistry, 142	2020	Blue	7	0.4062
Stavi I. (2021)	Stavi I.; Yizhaq H.; Szitenberg A.; Zaady E.	Patch-Scale To Hillslope-Scale Geodiversity Alleviates Susceptibility Of Dryland Ecosystems To Climate Change: Insights From The Israeli Negev	Current Opinion In Environmental Sustainability, 50, 129–137	2021	Blue	2	0.338
Schreiner-Mcgraw A.P. (2019)	Schreiner-Mcgraw A.P.; Ajami H.; Vivoni E.R.	Extreme Weather Events And Transmission Losses In Arid Streams	Environmental Research Letters, 14(8)	2019	Blue	8	0.2637
Bharucha Z.P. (2019)	Bharucha Z.P.	This Is What Nature Has Become: Tracing Climate And Water Narratives In India's Rainfed Drylands	Geoforum, 101, 285–293	2019	Blue	7	0.2308
Zhang Y. (2022)	Zhang Y.; Gentine P.; Luo X.; Lian X.; Liu Y.; Zhou S.; Michalak A.M.; Sun W.; Fisher J.B.; Piao S.; Keenan T.F.	Increasing Sensitivity Of Dryland Vegetation Greenness To Precipitation Due To Rising Atmospheric Co2	Nature Communications, 13(1)	2022	Blue	0	0
Delgado-Baquerizo M. (2018)	Delgado-Baquerizo M.; Maestre F.T.; Eldridge D.J.; Bowker M.A.; Jeffries T.C.; Singh B.K.	Biocrust-Forming Mosses Mitigate The Impact Of Aridity On Soil Microbial Communities In Drylands: Observational Evidence From Three Continents	New Phytologist, 220(3), 824–835	2018	Yellow	30	15.429
Baldauf S. (2021)	Baldauf S.; Porada P.; Raggio J.; Maestre F.T.; Tietjen B.	Relative Humidity Predominantly Determines Long-Term Biocrust-Forming Lichen Cover In Drylands Under Climate Change	Journal Of Ecology, 109(3), 1370–1385	2021	Yellow	8	13.521

Table A2. *Cont.*

VOS Label	Authors	Title	Journal	Year	Cluster	Citations	Norm. Citations
Eldridge D.J. (2020)	Eldridge D.J.; Delgado-Baquerizo M.; Quero J.L.; Ochoa V.; Gozalo B.; García-Palacios P.; Escolar C.; García-Gómez M.; Prina A.; Bowker M.A.; Bran D.E.; Castro I.; Cea A.; Derak M.; Espinosa C.I.; Florentino A.; Gaitán J.J.; Gatica G.; Gómez-González S.; Ghiloufi W.; Gutierrez J.R.; Gusmán-Montalván E.; Hernández R.M.; Hughes F.M.; Muiño W.; Monerris J.; Ospina A.; Ramírez D.A.; Ribas-Fernández Y.A.; Romão R.L.; Torres-Díaz C.; Koen T.B.; Maestre F.T.	Surface Indicators Are Correlated With Soil Multifunctionality In Global Drylands	Journal Of Applied Ecology, 57(2), 424–435	2020	Yellow	21	12.188
Krichels A.H. (2022)	Krichels A.H.; Homyak P.M.; Aronson E.L.; Sickman J.O.; Botthoff J.; Shulman H.; Piper S.; Andrews H.M.; Jenerette G.D.	Rapid Nitrate Reduction Produces Pulsed No And N2o Emissions Following Wetting Of Dryland Soils	Biogeochemistry, 158(2), 233–250	2022	Yellow	3	3.5
Delgado-Baquerizo M. (2020)	Delgado-Baquerizo M.; Doulcier G.; Eldridge D.J.; Stouffer D.B.; Maestre F.T.; Wang J.; Powell J.R.; Jeffries T.C.; Singh B.K.	Increases In Aridity Lead To Drastic Shifts In The Assembly Of Dryland Complex Microbial Networks	Land Degradation And Development, 31(3), 346–355	2020	Yellow	15	0.8705
Liang C. (2020)	Liang C.; Chen T.; Dolman H.; Shi T.; Wei X.; Xu J.; Hagan D.F.T.	Drying And Wetting Trends And Vegetation Covariations In The Drylands Of China	Water (Switzerland), 12(4)	2020	Yellow	6	0.3482
Tfwala C.M. (2021)	Tfwala C.M.; Mengistu A.G.; Ukoh Haka I.B.; Van Rensburg L.D.; Du Preez C.C.	Seasonal Variations Of Transpiration Efficiency Coefficient Of Irrigated Wheat	Heliyon, 7(2)	2021	Yellow	2	0.338
Suich H. (2017)	Suich H.; Boardman J.	Wheat Growing And Changing Farming Systems In South African Dryland Margins: The Case Of The Sneeuberg, South Africa	Land Degradation And Development, 28(1), 57–64	2017	Yellow	2	0.0755
Brendel A.S. (2020)	Brendel A.S.; Del Barrio R.A.; Mora F.; León E.A.O.; Flores J.R.; Campoy J.A.	Current Agro-Climatic Potential Of Patagonia Shaped By Thermal And Hydric Patterns	Theoretical And Applied Climatology, 142(3–4), 855–868	2020	Yellow	1	0.058
Hansen N.C. (2012)	Hansen N.C.; Allen B.L.; Baumhardt R.L.; Lyon D.J.	Research Achievements And Adoption Of No-Till, Dryland Cropping In The Semi-Arid U.S. Great Plains	Field Crops Research, 132, 196–203	2012	Purple	122	1
Harper R.J. (2014)	Harper R.J.; Sochacki S.J.; Smettem K.R.J.; Robinson N.	Managing Water In Agricultural Landscapes With Short-Rotation Biomass Plantations	Gcb Bioenergy, 6(5), 544–555	2014	Purple	17	1

Table A2. *Cont.*

VOS Label	Authors	Title	Journal	Year	Cluster	Citations	Norm. Citations
Wang E. (2009)	Wang E.; Cresswell H.; Bryan B.; Glover M.; King D.	Modelling Farming Systems Performance At Catchment And Regional Scales To Support Natural Resource Management	Njas - Wageningen Journal Of Life Sciences, 57(1), 101–108	2009	Purple	22	0.5057
Hart B. (2020)	Hart B.; Walker G.; Katupitiya A.; Doolan J.	Salinity Management In The Murray-Darling Basin, Australia	Water (Switzerland), 12(6)	2020	Purple	8	0.4643
Acharya P. (2019)	Acharya P.; Biradar C.; Louhaichi M.; Ghosh S.; Hassan S.; Moyo H.; Sarker A.	Finding A Suitable Niche For Cultivating Cactus Pear (Opuntia Ficus-Indica) As An Integrated Crop In Resilient Dryland Agroecosystems Of India	Sustainability (Switzerland), 11(21)	2019	Purple	6	0.1978
Wang Y. (2018)	Wang Y.; Gao F.; Yang J.; Zhao J.; Wang X.; Gao G.; Zhang R.; Jia Z.	Spatio-Temporal Variation In Dryland Wheat Yield In Northern Chinese Areas: Relationship With Precipitation, Temperature And Evapotranspiration	Sustainability (Switzerland), 10(12)	2018	Purple	3	0.1543

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2. Volkov, A.; Žičkienė, A.; Morkunas, M.; Baležentis, T.; Ribašauskienė, E.; Streimikiene, D. A Multi-Criteria Approach for Assessing the Economic Resilience of Agriculture: The Case of Lithuania. *Sustainability* **2021**, *13*, 2370. [CrossRef]
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12. Cabrera, J.S.; Lee, H.S. Impacts of Climate Change on Flood-Prone Areas in Davao Oriental, Philippines. *Water* **2018**, *10*, 893. [CrossRef]
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Article

Impacts of Floods on Agriculture-Dependent Livelihoods in Sub-Saharan Africa: An Assessment from Multiple Geo-Ecological Zones

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Abstract: Surging extreme events, particularly floods, have stimulated growing research on their epidemiology, management, and effects on livelihoods in Sub-Saharan Africa (SSA), especially for agriculture-dependent households. Unfortunately, the topical literature is still characterized by independent, isolated cases, with limited relevance to understanding common flood effects across geographical space and time. We bridge this knowledge gap by analyzing the effects of multiple cases of flash, coastal and riverine-cum-pluvial ('complex') floods on agriculture-dependent livelihoods in three (Sudano Sahelian, Coastal and Western Highlands) geo-ecological zones in Cameroon. The analysis makes use of a sample of 2134 flood victims (1000 of them in the Sudano-Sahelian, 242 in the Coastal, and 892 in the Western Highlands zones) of 26 independent community floods: 11 in the Sudano-Sahelian, 3 in the Coastal, and 12 in the Western Highlands zone. Irrespective of flood type and geo-ecology, agriculture-dependent livelihoods were gravely impaired. However, the impacts on livelihoods and public goods (such as road or communication systems) significantly varied in the different geo-ecological zones. The study concludes with the need to include context-specificity in the flood impact assessment equation, while identifying common effects, as is the case with agriculture in this study. We emphasize the need to up-scale and comparatively analyze flood effects across space and time to better inform flood management policies across SSA.

Keywords: floods; agriculture-dependent livelihoods; impacts; geo-ecological zones; sub-Saharan Africa

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1. Introduction

Livelihoods around the world are affected by increasing extreme events, which depend on several factors; these include vulnerability, hazard intensity and duration, risk perceptions and exposure [1–11], system resilience and response capacity, weak disaster management institutions [12–14], and ineffective coping mechanisms [1,3,13]. Other influencing reasons include the degree of correlation in the affected group (that is, whether the event is idiosyncratic or covariate), and whether the management strategies are applied *ex-post* (before the event) or *ex-ante* (after the event) [15]. Overall, the effects of extreme events on the environment and on the livelihoods of affected populations are negative [15–20].

The concept of livelihood has gained importance in the last three decades and has been the focus of discourse across disciplines on poverty reduction, development policy, sustainable resource management, and climate change [21]. Defined in a broader sense, a livelihood comprises the capabilities, assets (including both material and social resources) and activities required for living. A livelihood is considered sustainable "when it can cope with and recover from stresses and shocks, maintain or enhance its capabilities and assets, while not undermining the natural resource base" ([22], p. 175).

Agriculture remains a major source of livelihoods, especially for rural households in developing countries [23,24]. Globally, approximately 2.5 billion people, of which 60% reside in developing countries, depend almost entirely on agriculture for their livelihoods, generating over half of the global food production on small farms [25]. Global agricultural production and agriculture-based livelihoods are particularly at risk, due to rising extreme events, such as floods and droughts [26]. Therefore, understanding the agriculture-dependent livelihoods–extreme events nexus, is relevant to developing resilience, adaptation, mitigation or coping strategies that can permit agrarian societies to survive as extreme events become more frequent [16,25].

The rapid surge of extreme events has stimulated research on their epidemiology and on their multifaceted effects concerning the economy [18], society [7,27], the environment [28,29] and livelihoods [10,15,19]. For instance, in the last seven decades, natural disasters have caused an estimated global economic loss of over USD 3 trillion, have inflicted over 1.3 million casualties, and impaired over 4.4 billion people [16]. Frequently reported effects include the loss of human and animal life, and the loss of livestock, crops, land, houses, and infrastructure. Furthermore, natural disasters force displacement [3,7–9,13,20,30,31], impair health conditions and disrupt the supply of critical services, such as electricity and medication [2,17–20]. These outcomes directly or indirectly interrupt livelihoods in the impacted communities. In 2020, EM-DAT, the international disaster database (see: www.emdat.be/), recorded 389 environmental disasters, which caused the loss of 15,080 human lives, affected 98.4 million people, and inflicted financial losses of over USD 171.3 billion [24].

Floods are one of the most frequent and virulent extreme events worldwide. Their frequency is linked to the consequences of climate change and socio-economic development [7,15,19,26]. For many decades, floods have accounted for most of the global effects of natural disasters on economic growth and livelihood outcomes [7–9]. In fact, flooding was the major source of recorded global disasters between 2000 and 2019; floods were also the second largest natural disaster after droughts, in terms of the total number of affected persons over the same period [7,9].

Floods have occupied the premier rank among global environmental disasters in the past twenty years in terms of the frequency of their occurrence; floods account for 44% of all the registered disaster events [7–9,26], and top the list of natural disasters in terms of economic damages: they cost USD 651 billion in this time-span [7]. Floods were only second to drought, with 1.6 billion people being affected worldwide [7,9].

Seven million people were affected by floods in Africa in 2020; this was the highest impact on record since 2006. The bulk of the effects are recorded in Sub-Saharan African (SSA) countries [32], in which the pervasive flood-related devastation of livelihoods is expected to surge as the frequency of events increases [33,34]; this is in a context characterized by a weak formal and informal institutional capacity for disaster management [28]. This is expected to retard economic and social change, in that it will scale back the attained progress in reducing poverty, and negatively affect the global capacity to achieve the sustainable development goals (SDGs) of the Global Agenda 2030 [35]. These expectations have provided the impetus for a strong flood research agenda in SSA [3,19,36,37].

One way to reduce flood effects in SSA is to develop an overarching policy agenda for flood management. For instance, the Sendai Framework for Disaster Risk Reduction (2015-30), one of the first major agreements of the post-2015 Global Agenda, supports countries in identifying and implementing concrete actions to protect development gains from the risk of various disasters (www.undrr.org/implementing-sendai-framework/what-sendai-framework, accessed on 15 January 2023). Such an overarching policy agenda for flood management will greatly benefit from empirical research and the identification of robust trends for all cases, space and time [11]. Understanding the impacts of flooding, beyond the individual case and the different geo-ecologies, provides valuable insight into effective policy decisions in SSA. In these areas, poverty is endemic and flooding severely impacts agriculture, which is the mainstay of most people in SSA [7,11]. The flood research landscape in Africa, and particularly in SSA, is flourishing [38]. Unfortunately, research on floods is dominated by isolated case studies [19], which provide limited insights and are of limited relevance for flood risk reduction, mitigation, and adaptation at national, regional and sub-continental levels. Comparative analyses still beg for attention. A shift towards multiple case studies that transcend geo-spatial limits can significantly influence flood management policy decisions at aggregate levels.

In this context, systematic analyses of nationally aggregated data can provide directives for both national and (sub) continent-wide policies; SSA urgently needs these, given her growing subjection to floods [16,32,39,40]. However, very little has been done to compare the effects of multiple floods, and even less across different geo-ecological zones. We narrow this knowledge gap by analyzing the effects of multiple flood types (e.g., flash, coastal and 'complex' or riverine-cum-pluvial) on agrarian livelihoods in Cameroon. The floods studied occurred independently of each other in three geo-ecological zones in Cameroon, that is, the Sudano-Sahelian, the Coastal (Humid Forest with Monomodal Rainfall), and the Western Highlands (Montane or Western High Plateau) zone. The three zones are marked by distinct specificities in terms of the frequency and triggers of flood disasters, and by distinct geographical characteristics. The underlying denominator for all the studied geo-ecological zones is the fact that agriculture is the main source of livelihoods for the rural population [41].

The major scientific contribution of this study is achieved by analyzing the effects of multiple, independent floods on agriculture-dependent livelihoods in three Cameroonian geo-ecological zones in a single study. Our contribution, therefore, provides initial reflections and insights on the effects of extreme events, particularly floods on agriculture-based livelihoods across space and time; it also stimulates reflections on possible (research and policy) perspectives to develop flood-resilient livelihood systems in communities in which agriculture is the mainstay. To achieve this, the study is guided by a central research question: Do the impacts of floods among agriculture-dependent livelihoods differ by geo-ecological zone?

Section 2 presents a concise overview of the impacts of floods on livelihoods. Then, Section 3 depicts the study sites in the three geo-ecological zones, as well as the sampling-cum-data collection approaches. In Section 4, demographic results are presented first, followed by the impacts of floods on livelihoods. Concluding remarks are summarized in Section 5.

2. Conceptual Framework for Assessing Flood Impacts on Livelihoods

2.1. Brief Outline of the Conceptual Sustainable Livelihood Framework

Since the 1970s, the farming system research approach has been continuously broadened to encompass a wider set of issues, resulting in the Sustainable Livelihoods Framework (SLF). The livelihoods approach offers a rounded, bottom-up perspective and strives for a more holistic, people-centered approach. Through the concepts of 'vulnerability' [42], 'sensitivity', and 'resilience' [43], the SLF also seeks to capture the hazards that (farm) households face, the shocks that these engender, and their capacities to respond to them [44].

The SLF integrates all the important aspects that affect livelihoods. A widely accepted definition stems from Chambers and Conway ([45], p. 7–8): "a livelihood comprises the capabilities, assets and activities required for a means of living". Capabilities refer to the set of alternates that an individual can attain with her/his/their economic, social, and personal characteristics. The SLF emphasizes the asset pentagon (see Figure 1), consisting of natural, physical, human, financial and social assets. Access to these assets, as well as to their efficient use, determine the resilience of the right-holders vis-à-vis extreme events. The asset pentagon is embedded in additional impacting factors, such as the 'vulnerability context' (e.g., demographic trends, depletion of natural resources, extreme events, etc.), 'structures and institutions' (e.g., gender roles, private and public disaster risk management frameworks), and 'intention and behavior' (e.g., agency resulting from perceived risks).

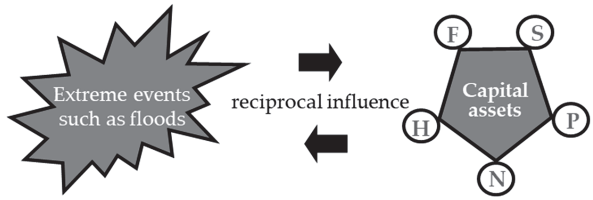

Figure 1. Capital asset pentagon of the SLF. Source: Excerpt from Buchenrieder and Möllers ([44], p. 18). Notes: S = Social capital, i.e., social networks. F = Own financial means and access to external finance. N = Natural resources, e.g., land. P = Physical assets. H = Human capital, e.g., labor, health.

2.2. Brief Literature Review on the Impacts of Flooding on Household Livelihoods

Irrespective of, and sometimes independent of literary positions and classification approaches [16], floods continue to have serious direct and indirect human, physical, social, economic, psychological and other effects on their victims. The most common direct effects include the destruction of houses, crops, livestock, agricultural land, loss of lives and forced displacement [1–3,8,19,23,24,29,36,46–51]. Indirect effects may include post traumatic/mental disorders, and an increased frequency of diseases. Floods increase vulnerability, especially in developing countries, increasing the exposure of people to other livelihood shocks, such as economic and political crises [19,47,50]. Floods can perpetuate poverty by damaging goods and possessions, by causing clean-up costs [49], and by causing the loss of livelihood resources, for example, as a result of forced migration [28,31,52]. Those who do not migrate due to place-based attachment [31], a lack of capacity [52] or information asymmetry about the possible outcome of forced environmental migration [28], often witness livelihood degradation. Floods, therefore, affect economic/financial capital accumulation directly by destroying productive assets, such as livestock and crops, and indirectly by engendering income loss from not being able to liquidate lost assets [27,53].

Floods can puncture the accumulation of human capital, especially for agriculture-dependent households. For instance, Zerihun and Befikadu [3] reported that floods in North Western Ethiopia affected the human capital of flood victims in the form of reduced health conditions, the destruction of education systems, as well as the loss of skilled labor. Saleh [47], as well as Musah and Akai [48], observed a high incidence of water-borne diseases, such as diarrhea, cholera, and jaundice, amongst children and the elderly after flood events in Bangladesh and Ghana, respectively.

Furthermore, floods may destroy social capital in the form of endogenous social networks and contribute to the degradation of (fragile) ecosystems. When floods destroy social networks, it has been further observed that this too results in generalized destitution and a sense of grief among people who have lost loved ones, with psycho-traumatic consequences [40].

In summary, floods render agriculture-dependent households and (agrarian) communities more vulnerable to any adverse climatic and livelihood-depriving events, such as sickness and food consumption fluctuations; thereby, floods aggravate poverty and weaken resilience capacities [24,29].

Floods impact food insecurity [24,46] directly through the loss of household and farm assets, e.g., stored crops and livestock [8,35], but also indirectly through the loss of labor, either to death or forced migration, or to soil destruction and land degradation [24]; these may cumulatively culminate in a decline in food production [23,47]. Land contamination may impair food production further and, therefore, income, especially for agrarian households and communities who then witness short and long-term household food insecurity [24,48].

By way of summary, shocks such as floods often expose poor agrarian communities to negative livelihood effects and vulnerabilities. However, the answer to whether the effects correspond across space and time needs further research. We use several case studies to understand the effects of floods on the livelihoods of victims across space (three geo-ecological zones) and time (independent events).

3. Materials and Methods

3.1. The Study Sites

In total, five geo-ecological zones are found in Cameroon (see Figure 2): (1) The Sudano-Sahelian zone, (2) the Western Highlands (or Montane) zone, (3) the Humid Forest with monomodal rainfall; (4) The Humid Forest with bimodal rainfall, and (5) the High Guinean Savanna, in this study known as the Coastal zone [54].

In all of these geo-ecological zones, Cameroon has witnessed a significant increase in the frequency of floods over the last three decades [15,39]. Specifically, the frequency has increased from three per annum, in the 1980s, to a current average of five and up to ten in urban areas [55]. In 2020 alone, flooding impacted over 193,000 persons in Cameroon [40]. The most recent flood occurred in mid-August 2022 in the Far North Region, affecting approximately 40,000 people. The flooding was caused by heavy rainfalls, which caused rivers to overflow and dikes to break (see: floodlist.com/africa/cameroon-floods-farnorth-october-2022, accessed on 19 December 2022).

This study is concerned with three flood types that occurred in three separate geo-ecological zones: 'Complex' floods in the Sudano-Sahelian zone, coastal floods in the Coastal zone, and Riverine floods in the Western Highlands. Coastal floods result from strong winds or storms in coastal areas during high tides when low-lying areas are flooded by sea water. Riverine floods are characterized by gradual riverbank overflows that emanate from extensive rainfall over an extended period of time [53]. The area affected by river floods will depend on the size of the river and the amount of rainfall. Pluvial (or flash) floods occur in flat areas where the terrain cannot absorb the rain water, causing puddles and ponds. Though similar to urban flooding, pluvial floods occur mostly in rural areas, with serious impacts on the agricultural gainful activities and properties in the area [14,41]. We use the term 'complex' to describe a simultaneous occurrence of flood types. Flooding in the Far North Region of Cameroon (the Sudano-Sahelian zone) is complex, in that it is always a mix of the flash, riverine and pluvial types [14,37,41,56].

Empirical studies were carried out in the following three (of the five) geo-ecological zones that are highly exposed to flooding in Cameroon: the Sudano-Sahelian zone that covers the North and Far North Region (Zone I), the Coastal zone that covers the Littoral and South-West Regions (Zone II), and the Western Highlands (or Montane) zone (Zone III) in the North-West Region [37].

The Sudano-Sahelian zone corresponds to Zone I in Figure 2 and is characterized by a mean temperature of 28 °C and an average rainfall of 850 mm per annum; it has a base saturation of around 70%, and high amounts of weatherable soils. Settlement is concentrated along the rivers Benoue and Logone, which further exposes the population to regular floods [14,41]. In addition, the Ladgo dam, initially constructed to generate electricity, is now a regular source of flooding due to rapid sedimentation and improper management [41]. This zone is prone to both droughts and floods [14,41].

The Coastal zone corresponds to Zone IV in Figure 2, and comprises the Littoral and South-West Regions (with Douala and Buea as capitals, respectively), plus the Coastal edge of the South Region. It is the most important industrial and cash crop-producing zone in Cameroon. Due to this fact, it has the highest population density, of 66 persons per square kilometer and a high rate of vegetation loss [57]. The key rivers in this zone, notably Wouri, Dibamba, Mungo, Sanaga, Ntem, Manyu and Meme, often exceed their banks in the rainy season and generate floodplains, particularly along the multiple sandy beaches and cliffs [57,58]. The area experiences an average amount of rainfall, with 10,287 mm per annum, and exhibits warm temperatures year-round, ranging from 27 °C to 32 °C [14].

Figure 2. Geo-ecological zones in Cameroon and regions covered. Source: DSDSR ([59], p. 113). Notes: Black boxes represent the study regions in the three selected geo-ecological zones, represented by the regional capitals Maroua, Buea and Bamenda, respectively.

The Western Highlands, also known as the Montane zone, corresponds to Zone III in Figure 2. It covers the administrative districts of the West and North-West Regions, with the regional capital cities: Bamenda and Bafoussam. This area is of remarkable geological diversity and includes the Bamoun Plateau, which extends to an altitude of approximately 1240 m, the Bamiléké Plateau, which reaches an altitude of 2740 m through Mount Bamboutos, and the volcanic plateaus of Bamenda, at approximately 1800 m [57]. The landscape is characterized by medium mountains, savannah vegetation, stepped plateaus, low basins and plains, and patchy remnants of gallery forests, due to rapid deforestation in the last five decades [14,60]. Subsistence agriculture carried out on the mountain slopes creates favorable conditions for the rapid accumulation of large amounts of water, resulting in flooded areas especially during the rainy season. Zone III exhibits an average temperature of 21 °C and an average rainfall of 2500 mm per year [14]. Combined with the high altitude (1000–3011 m a.s.l.), this zone is frequently prone to flooding during the rainy season [14,41].

The selection of case study sites was accomplished In this manner for the following reasons: First, Cameroon is fondly called 'Africa in miniature', due to the presence of multiple representative geo-ecological zones. Second, it is also one of the regions most affected by natural disasters in SSA [38,40,61], thus lending itself as a good choice for a comparative study. For instance, floods negatively affect, on average, 120,000 people every year, approximately 0.5% of the total population of Cameroon [62]. According to the CCKP [63], 65.4% (n = 17) of the registered major natural hazards in Cameroon are floods (1980–2020). This official estimate seems very conservative, since according to the data from the city administration, the economic capital Douala alone experienced over 300 floods between 1980 and 2014 [64]. Third, the three studied geo-ecological zones are those most affected by floods in Cameroon [40], and their economy is predominantly agriculture based [41]. Such a choice increases the potential of generated knowledge to inform practical flood policy decisions, with a focus on agriculture-dependent households. Lastly, each geo-ecological zone had recently experienced floods, for which our research team collected coherent impact assessment data, allowing for comparisons across the three geo-ecological zones [15,37,39] (see Appendix A for a schedule of floods and data collection periods).

The mixed-method design was adopted for all the original studies, during which quantitative and qualitative data were collected from flood victims in all three zones through face-to-face interviews. Overall, ten trained enumerators were involved in quantitative data collection using structured and pretested questionnaires. The questionnaires were tested on 5–10 respondents in the entry communities, to allow for adjustments before collecting data. A total of 2134 victims from 26 communities who were affected by five independent floods participated in the survey. These included 1000 flood victims from 11 communities in the Sudano-Sahelian zone (46.9%), 242 from 3 communities in the Coastal Zone (11.3%), and 892 from 12 communities in the Western Highlands (41.8%). The household heads responded to the questions. We assumed that they were well placed to recall the flood impacts. However, interviews took place at the homesteads, and other household members could participate.

3.2. Sampling Approaches

Only flood-affected households were interviewed to capture the direct flood effects. In each community, a sampling frame was obtained from the relevant local government authorities. From the list, flood-affected households were then identified, sampled, and interviewed.

Simple random sampling was applied to select the final sample only in the Far North Region (Sudano-Sahelian Zone I), where the number of victims was high; this was initially estimated at 20,000 [37]. A census approach was applied in all the flood communities, given the relatively small numbers of victims. Only victims who remained in the area and were willing to participate in the study were interviewed. The participation rate was between 90% and 100% for all flood victims, except in the Sudano-Sahelian zone, where our sample is estimated to be 5% of all those who were affected in the sampled villages by the selected floods.

In each community in the Sudano-Sahelian zone, the names/numbers of the affected households on the list were written on pieces of paper and randomly selected for interviews. Random selection, therefore, ended when the 1000th respondent was identified. A target of 1000 was set to optimize the shortcomings of time and logistics without losing quality. Household heads that were unavailable at the time of interview were replaced, still applying the randomization technique to the rest of the unselected households in the replacement list.

A mixed-method design was adopted for all the original studies, during which quantitative and qualitative data were collected from the flood victims in all three zones between 2012 and 2017. Overall, ten trained enumerators were involved in quantitative data collection using structured and pretested questionnaires. The questionnaires were tested on 5–10 respondents in the entry communities to allow for adjustments before collecting data. Data were collected after flood events, but not more than four months after the flood event. This upper limit was set to reduce difficulties with recollection, which comes with long waiting periods [14]. The interviews and data recording took place at the homesteads of the interviewees.

The key instrument used for data collection (structured questionnaire) comprised of four sections. Section one described the characteristics of the household head and his/her household; section two recorded the impact of the shock at the household level; section three captured the impact of floods at individual, household, and community levels; and section four identified the types of household response mechanisms. Each interview lasted between 10 and 15 min, depending on the level of damage incurred by the household. The structured questionnaires were complemented by field observations and key informant interviews. The collected data were entered, cleaned, and analyzed using SPSS (Statistical Package for Social Sciences), version 25.0. At a 95% confidence interval ($\alpha = 0.05$), both descriptive and statistical analyses are reported. The Chi-square distribution was the main statistical test used to compare the flood damage to households in the different zones.

ANOVA was also used to compare the age of the household heads, household sizes and the estimated monthly income of households in the different zones. As an analytical approach, ANOVA detects differences between (experimental) group means for selected variables (in this case, flood effects), with respect to one or more independent variables (geo-ecological zones); this was based on the assumptions that (1) the value of each observation is not influenced by that of other observations, and that (2) ANOVA is a good statistical application even for skewed data, as long as the sample size is large [65]. Sawyer [65] and Daniel [66] suggest a minimum group sample size of 30. As the size of each group meets this minimum criterion, ANOVA subdues any violations of homogeneity in variance assumptions.

The results were compared for households across geo-ecological zones. Given that these studies were carried out independently of each other, and that slight modifications were made to respond to contextual realities, only variables relevant to the respective capital assets captured in all the studies were compared. Therefore, for instance, financial capital was not analyzed. Where appropriate, the F-statistic was applied to explore the mean distribution of corresponding variables under the null hypothesis assumption, while the t-test was used to make statistical inferences on the differences of dependent variables between the geo-ecological zones [65]. A comparative analysis of the results between the three geo-ecological zones is presented and discussed in the next section.

3.3. Sample Size

A total of 2134 victims from 26 communities who were affected by five independent floods participated in the survey. These included 1000 flood victims from 11 communities in the Sudano-Sahelian zone (46.9%), 242 from 3 communities in the Coastal Zone (11.3%), and 892 from 12 communities in the Western Highlands (41.8%). The household heads responded to the questions. We assume that they are well placed to recall flood impacts. However, interviews took place at the homesteads, and other household members could participate. Table A1 in the Appendix A summarizes the database.

4. Results and Discussion

4.1. Descriptive Socio-Economic Household Results

The data indicated gender differences across the three geo-ecological zones. The majority of respondents (household heads) in both the Sudano-Sahelian zone (Zone I in Figure 2) and the Coastal zone (II) were male (close to 72% and 61%, respectively), while the majority of the respondents in the Western Highlands (Zone III) were female (over 53%). Although patriarchal systems exist in all zones, it seems to be stronger in the Moslem-dominated Zone I, compared to the Christian-dominated Zone II. These gender-based differences can have implications on flood perception, resilience, and the eventual impacts on livelihoods, given that women generally have limited access to, and control over, the resources needed to prepare for, or respond to extreme events [8,67].

With respect to educational achievement, over 38% of the entire sample had finished primary school (64% in Zone I, 38% in II, as well as III). Approximately 17% of the respondents in Zone I, 33% in Zone II, and 44% in Zone III had completed secondary school education. Buchenrieder et al. [8] and Shah et al. [56] report that differences in educational levels, for instance, will have an effect on the management approach to floods and their effects on livelihoods. Previous studies indicate that persons or communities with low educational levels tend to adopt more low-tech and ad hoc flood management strategies, such as temporary migration, gift economy, and mutual aid [8]; meanwhile, more educated ones are likely to adopt high-tech solutions, such as early warning systems and the construction of retention dikes [5,15,54].

The main sectors of employment are summarized in Figure 3. It reveals differences across zones. While only a slight difference was observed for the Sudano-Sahelian zone (Zone I: 49% employed in the farm sector and 51% in the non-farm sector), the gap was greater in the Coastal zone (Zone II: 20% employed in the farm sector and 80% in the non-farm sector) and the Western Highlands (Zone III: 59% employed in the farm and 41% in the non-farm sector. It is plausible to assume that the border with Nigeria in Zone I and the economic capital of Douala, which hosts a seaport nearby Zone 2, encourage non-farm activities. In addition, the damage to the agricultural income base, due to the increasingly experienced floods, might create disincentives to engage in agriculture [2,8,19,41]. Zone III is land-locked and driven by an agrarian economy, with fewer non-farm opportunities [15]. All households, irrespective of the main income-creating occupation, depend at least partly on agriculture for their livelihoods. Any flood effects on the agricultural sector are, therefore, likely to influence livelihood outcomes in the studied communities, given their reliance on agriculture for subsistence and cash income [14,41].

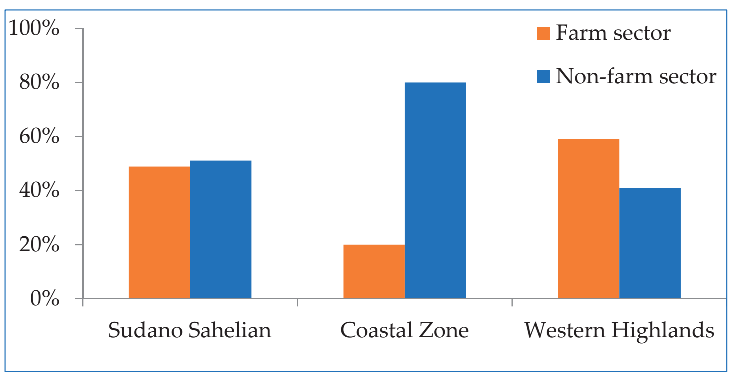

Figure 3. Main sector of employment of household head, per geo-ecological zone.

Analyses of additional socio-demographic variables are presented in Table 1. The mean age of the respondents was significantly higher in the Coastal zone (Zone II), compared to the Western Highlands (Zone III) and the Sudano-Sahelian zone (Zone I): 45 years, 38 years, and 33 years, respectively. The mean age for the entire sample (39 years) is not very different from the mean of 41 years reported in a recent study on Cameroon [8]. Differences were further observed in mean household sizes, with Zone III recording the largest household size, followed by Zone I and then Zone II (8, 7, and 6 household members, respectively). The mean monthly household income in Zone III was significantly higher compared to Zone I and Zone II (FCFA183,710 [US$ 288], compared to FCFA55,780 [US$ 87.5], and FCFA89,300 [US$ 140.1], respectively). It is, therefore, expected that, given the older age of the household heads and the higher household incomes, the flood victims in the Western Highlands (Zone III) will better cope with floods, compared to those in the other geo-ecological zones.

Table 1. Demographic characteristics of households by geo-ecological zone.

Variables	Geo-Ecological Zone	Mean	Std. Deviation	ANOVA
Age of household head (in years)	Sudano Sahelian (I) Coastal (II) Western Highlands (III)	32.72 45.47 37.68	11.067 12.096 14.172	F = 99.783 $p = 0.000$
Household size (in persons)	Sudano Sahelian (I) Coastal (II) Western Highlands (III)	7 6 8	6 3 5	F = 24.729 $p = 0.000$
Estimated monthly Income (in FCFA)	Sudano Sahelian (I) Coastal (II) Western Highlands (III)	55,780 89,300 183,710	28,810 88,470 351,430	F = 67.837 $p = 0.000$

Note: 1 US$ = 637.25 FCFA (www.xe.com, 14 August 2022).

4.2. Impact of Floods on Household Livelihoods

Subjective responses from respondents revealed that most of them perceived the impacts of the different floods as highly negative, irrespective of the year and place of occurrence (74% in the Sudano-Sahelian, 49% in the Coastal, and 86% in the Western Highlands zone) (Figure 4). To enhance the consistency in quantifying losses for the multiple case studies in different geo-ecological zones and largely in line with the capital portfolio of the SLF [22], we limit the analysis to (1) loss of productive capital, (2) effects on human capital, and (3) damage to private and public property, such as houses and infrastructure.

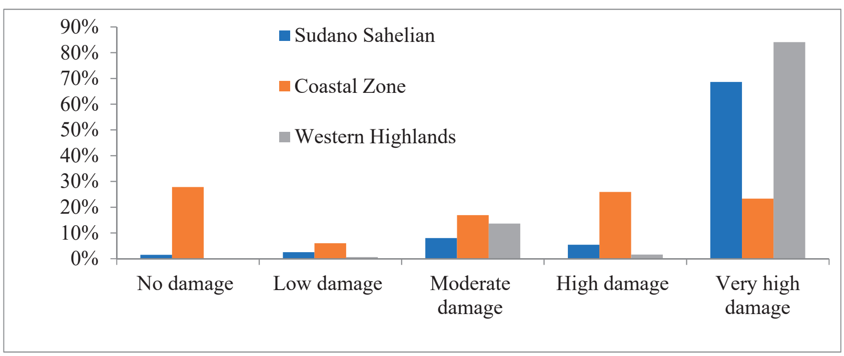

Figure 4. Level of flood damage to households, percentage of household heads.

4.2.1. Loss of Productive Assets

Obviously, agriculture-dependent households depend on arable land for production. The destruction of farmland by flooding was thus considered a major disaster. Erosion of the top soil due to flooding occurred in all zones, which rendered land less fit for farming activities. However, this was more intense in Zones I and II than in Zone III.

Other productive assets, whose losses were captured in all case studies related to the loss of livestock and damage to crops (Figure 5), were noted. The livestock losses after flooding were higher in the Western Highlands (by 98% of respondents) and the Sudano-Sahelian zone (by over 95% of respondents), as opposed to only 47% of the household respondents in the Coastal zone. The scenario was different with regard to crop damages. Significantly higher crop damages were recorded in the Sudano-Sahelian zone (reported by over 88%), the Coastal zone (over 53%) and lastly the Western Highlands (34% of the households). Overall, the farm sector (both crop and livestock) was seriously affected by the floods across all geo-ecological zones, even if the effects were significantly higher in the Sudano-Sahelian zone.

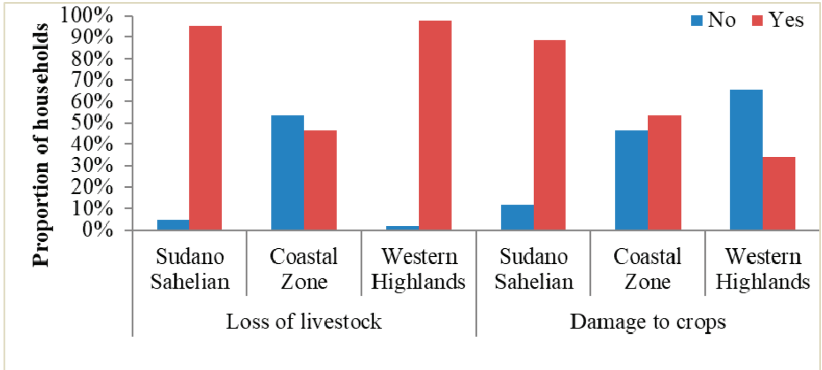

Figure 5. Loss of and damage to household productive assets, share of households. Notes: Chi-square livestock = 622.77, $p = 0.000$; Chi-square crop = 537.676, $p = 0.000$.

In total, 72% of all respondents reported generally impaired economic activities due to the experienced floods. The share of reports, however, varied in Zone III, Zone II, and I (85%, 69% and 62%, respectively).

4.2.2. Flood Effects on Human Capital

Human capital was captured in the 26 case studies, through health challenges, injury, and death, attributable to floods (Table 2). Empirical results suggest that less than 33% of all the respondents experienced deteriorating health conditions after floods, irrespective of the geo-ecological zone. The most common health deficit observed was diarrhea, emanating from contaminated drinking water sources. This effect was reported more often in the Coastal zone (57.5%), compared to the Sudano-Sahelian and Western Highlands zones (29% and 12%, respectively). Consistent with the previous results (e.g., [27,54]), a higher share of respondents in Zone I reported physical injuries from floods, compared to Zones II and III (28% and 19.5%, respectively). However, the death of household members as a result of the flooding was higher in Zone III than in Zones I and II (74%, 49% and 13%, respectively). Although the cumulative human capital effects are high for all the geo-ecological zones, the specific effects on human capital seem to vary. This may be attributed to varying levels of preparedness and disaster management capacity; nevertheless, this would have to be investigated further.

Table 2. Flood effect on human capital.

Human Capital Variables	Geo-Ecological Zone	In %		Chi-Sqaure
		No	Yes	
Increase in sickness	Sudano Sahelian (I)	70.9	29.1	$X^2 = 211.054$ $p = 0.019$
	Coastal (II)	42.5	57.5	
	Western Highlands (III)	88.2	11.8	
Physical injury	Sudano Sahelian (I)	72.0	28.0	$X^2 = 65.79$ $p = 0.000$
	Coastal (II)	80.5	19.5	
	Western Highlands (III)	88.3	11.7	
Loss of life from direct flooding	Sudano Sahelian (I)	51.4	48.6	$X^2 = 298.105$ $p = 0.000$
	Coastal (II)	86.8	13.2	
	Western Highlands (III)	26.2	73.8	
Loss of economic activities	Sudano Sahelian (I)	37.9	62.1	$X^2 = 108.685$ $p = 0.000$
	Coastal (II)	30.8	69.2	
	Western Highlands (III)	14.8	85.2	

4.2.3. Damage to Property

Figure 6 presents the summary of damages to private and public property across all the case studies and by geo-ecological zones. A significantly higher proportion of respondents in the Sudano-Sahelian zone stated to have not experienced property damages after floods, compared to their counterparts in the Coastal and the Western Highlands zones (94%, 23%, and 86%, respectively). Observations during data collection revealed that most structures in Zones I and II, particularly housing, were of rather poor quality, rendering them more vulnerable and susceptible to flood damages than households in Zone III. Bang et al. [41] attribute high property damage in Zone I to the highly weatherable soils that are particularly vulnerable to frequent floods. The Western Highlands (Zone III) suffered more from damage to public infrastructure, particularly roads, when compared to Zones II and I (83%, 50% and 59%, respectively). Field observations confirmed this trend in property damages in the three geo-ecological zones.

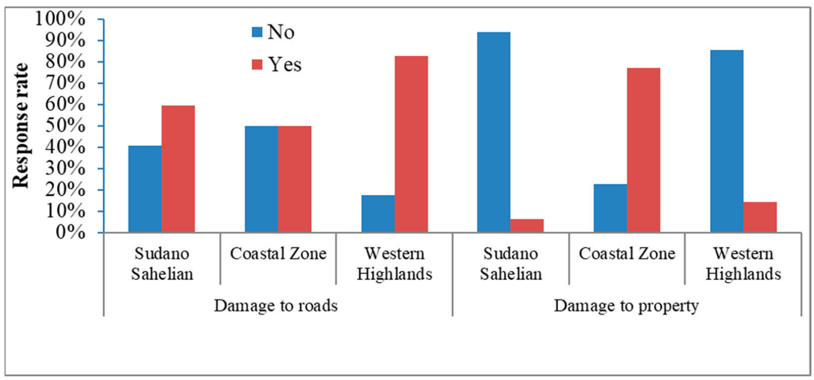

Figure 6. Damage to infrastructure. Notes: Chi-square livestock = 622.77, p = 0.000; Chi-square crop = 537.676, p = 0.000.

4.3. Discussion

The growing research on floods in SSA has greatly neglected the modeling of multiple floods and their impacts on livelihoods across space and time. We have contributed to this vacuum by analyzing the effects of five independent case study floods that affected 26 communities located in three geo-ecological zones in Cameroon; these floods occurred between 2012 and 2017.

The majority of the respondents (household heads) in two of the three geo-ecological zones were men. Their share was significantly higher for the Sudano-Sahelian zone (72%) and the Coastal zone (62%, p = 0.000). While male household dominance is sustained by a strong patriarchal system in Cameroon [39], the fact that household heads are more often male in the Sudano-Sahelian Zone might be linked to gender roles based on Islam [68]. Nevertheless, it also could simply be a result of men being more present at the homestead in this zone due to their on-farm income earning activities. Including gender differences is, therefore, central for effective flood preparedness and management in all of the studied geo-ecological zones. A reasonable proportion of the respondents (victims) had only primary education (almost two thirds and one-third in Zone I and II and III, respectively). Both statistics fall below the national literacy rate of 77.1%, signaling that those hit by extreme events, such as floods, have most often only finished primary school (see also [38]). School education may influence the perception of the victims vis-à-vis the offered risk management schemes and the willingness to adopt them [8]. However, differences across zones suggest different pathways towards flood risk preparedness and management, as high-tech solutions are likely to be less feasible for Zone I, compared to Zone II and III. Over 60% of all the respondents were married with family. This result is in favor of also propagating informal, endogenous, community-based approaches to flood management in SSA (as pointed out in [37,69]). Such an approach can compensate, to some degree, for the formal institutional deficits identified.

The agricultural sector was highly affected by floods, irrespective of the community or geo-ecological zone. The loss of livestock (95%, 47%, and 98%) and on-farm crop damages (88%, 53%, and 34%) were reported as a result of flooding in Zones I, II and III, respectively. Usually, stored seeds are also destroyed. However, the effects were consistently and significantly higher in the Sudano-Sahelian zone (I), compared to the Coastal and the Western Highlands zones (II and III). These findings relate with the works of [2,15,19,47,50], who contend that floods cause severe problems in all farm regions. Ainuddin et al. [4], for instance, report a 98.3% loss of crops in the North Western Zone of Ethiopia following flood events. Zhang et al. [70] report similar trends across China, with no firm spatiotemporal pattern of flood-destroyed crops across regions. Furthermore, flood effects on livestock and crops translate into subsistence and monetary income losses. This directly and indirectly decreases access to food, resulting in short- and long-term food insecurity in all the geo-ecological zones (see also [3,46,48,49]).

Flood effects on human capital are high across the board, but the specific type seems to vary notably among the three geo-ecological zones. In terms of human capital losses, approximately one-third of the sample reported an increase in health hazards after flooding. The most common health issue was diarrhea, which was reported by almost 56% of the respondents in the Coastal zone. Rising health hazards from flooding have also been reported in other recent studies in SSA (e.g., [1,27,54]). For instance, Suhr and Steinert [27] find that the majority of studies point to an increased risk of infection with cholera, scabies, and other diseases from floods, based on their systematic review of 2603 studies on the epidemiology of floods in SSA.

A significantly higher proportion of the household members in the Sudano-Sahelian zone (28%) reported physical injuries from floods compared to the Coastal and the Western Highlands zones, probably due to the poor quality of housing and road infrastructure, whose damage might have inflicted injuries on the victims [34,40] as they easily succumb to floods. This is plausible, given that the Sudano-Sahelian zone hosts the two poorest regions in Cameroon [41,53]. Njogu [53] contends that flood effects on infrastructure in this zone are a combined effect of high poverty rates, and social, biophysical and place vulnerability.

Many scholars (e.g., [8,11,17–19,30,55]) have also revealed that the death of victims is the most devastating consequence of natural disasters. More deaths from flooding were recorded in the Western Highlands (Zone III) than Zones I and II (see Table 2). This is probably due to a lack of experience with floods, which can lead to inadequate preparedness. Nevertheless, this finding corroborates the existing evidence that flash floods account for the highest average mortality among all flood types, even if spatial variations exist [71]. It is likely that experiential knowledge is at work, especially in Zones I and III, where flood frequency is higher [40] and community-based strategies have been developed to cope with the frequent occurrence of floods [1,8,37,41].

A greater proportion of all households reported impaired economic activities. However, economic loss was significantly higher for the households in the Western Highlands (III) than the Coastal (II) and the Sudano-Sahelian (I) zones (85%, 69% and 62%, respectively). We might see here a combined effect of inexperience, inadequate flood preparedness, and the possible damage of rapid, onset floods on agriculture, on which a majority of livelihoods in Zone III depend [8,14,23]. Economic losses from floods were reported in a study of six regional floods in Bangladesh between 2004 and 2007, specifically in the form of income and employment losses from the agricultural sector [72]. Differences in economic losses across case studies reiterate the importance of contextualizing variables for capturing the economic effects of floods. However, all studies report negative outcomes, irrespective of the measurement variables applied.

A significantly higher proportion of households in the Sudano-Sahelian zone reported damages to physical assets after floods, compared to the Coastal and the Western Highlands zones (94%, 23%, and 86%, respectively). Due to the hilly nature of the terrain in the Western Highlands (Zone III), the damage to roads was more severe when compared to Zone II and I (83%, 50%, and 59%, respectively). The study of Okunola [73] in South Africa also recorded significant damages to homesteads and public infrastructure, as a result of the April 2022 floods that swept across Kwa Zulu-Natal Province. Over 2000 houses and 4000 'informal' homes or shacks were severely damaged. Roads, more than 200 schools, and communication, water, and electricity systems were impaired. Similar results have been reported for Malawi [53], for dairy farm infrastructure in New Zealand [74], and for agricultural land damage after floods in Pakistan [75]. Despite differences in the physical farm assets, they were impaired by floods, with the effects seemingly related to the resilience of the critical infrastructure prior to the floods.

5. Conclusions

Very often, floods inflict negative effects on livelihoods, infrastructure, and ecosystems. Flood risk management is particularly important in SSA where (1) poverty is endemic, (2) early warning systems usually do not exist, and (3) the capacity of disaster management institutions is weak, dysfunctional, or simply absent. In this context, this article contributes to the growing literature on floods and livelihoods in SSA, by drawing on a sample of 2134 victims of independent floods in 26 communities; this was in order to examine the effects of multiple floods across three geo-ecological zones in Cameroon on agriculture-dependent livelihoods. The results led to a number of conclusions.

First, agriculture-dependent livelihoods were negatively affected across all the geo-ecological zones, albeit at different magnitudes. This seems normal, given that agriculture is the major source of livelihoods in the three studied geo-ecological conditions. Second, apart from economic losses, which were high in all the geo-ecological zones, a high regional variance was observed for other parameters, such health hazards, physical injuries, and the loss of human lives. This seems to suggest that the contextual (specific geo-ecologic) approach to understanding floods and their impacts should be further strengthened. In our study, the negative effects were more pronounced in the Sudano-Sahelian zone, with the lowest average annual rainfall; this is compared to the Coastal and Western Highlands zones, with a higher average rainfall. We assume that this is due to the high soil saturation and weatherable soil quality, and the less resilient construction of the houses. Third, flood-related deaths were significantly higher in the Western Highlands, compared to the Coastal and the Sudano-Sahelian zones; this is probably due to a lower flood risk perception, which may have caused inadequate preparedness.

This study, therefore, demonstrates how analyzing flood effects across space and time can provide insights into strategies that enhance broad-based efforts towards preventing, mitigating, managing, and developing private and public sector resilience against floods. The findings suggest that national and international policies (e.g., the Sendai Framework for Disaster Risk Reduction) need to be flexible enough to introduce contextual specificities into successful flood management. In other words, establishing broad-based flood policies can benefit from local realities, which differ across geo-ecological zones. However, as observed in this study, some aspects (agricultural damages) can be consistently similar across geographic space and time. Forging ahead with such a research agenda could generate vital insights into the area of study, which can support SSA countries and the subcontinent to develop and implement successful flood management policies; these are urgently required to deal with the surging number of floods and their effects.

Expanding this research agenda to other extreme events, such as droughts, whose frequency has also increased over the past 50 years [76], can support the continent in developing informed disaster preparedness and management policies; these are needed to shape disaster management in a continent characterized by a weak state and with a market capacity for disaster risk reduction. For such a research agenda to have an optimal impact, the need to harmonize data collection instruments and methods across space and time for effective comparisons cannot be overemphasized. This is a prerequisite for making policy suggestions to support SSA's flood risk reduction capacity, consolidating its achievements towards the globally designed Sustainable Development Goals, while reducing the harm caused to agriculture-dependent households.

Author Contributions: R.A.B. coordinated the work, from field research to the paper write up. He also interpreted the results and made conclusive suggestions. K.A.N. participated in the field data collection and ran the analysis. G.R.B. and J.N.K. reviewed the literature and critically commented on the multiple drafts. All authors contributed to critically fine-tuning the paper. All authors have read and agreed to the published version of the manuscript.

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Appendix A

Table A1. Schedule of floods and data collection periods.

Geo-Ecological Zone	Community	Respondents	Flood Date	Data Collection Date
Sudano-Sahelian zone (Zone I)	Bazala	148	August 2016	November 2016–January 2017
	Gazawa	99		
	Kaikai	82		
	Gobo	74		
	Katoual	56		
	Maga	113		
	Mora	86		
	Pouss	107		
	Ziling	71		
	Zoubouk	78		
	Zongoya	86		
	Total	**1000**		
Coastal zone (Zone II)	Bekora	68	September 2016	December 2016
	Clerks quarters	69		
	Motowoh	105		
	Total	**242**		
Western Highlands zone (Zone III)	Baba I	71	September 2015	October 2015
	Babessi	77	September 2012	December 2012
	Gayama	92	August 2017	October–November 2017
	Kpep	70		
	Akum	105		
	Ambo	62		
	Bado	60		
	Edzong	67		
	Ifung	70		
	Munka	84		
	Munkep	60		
	Ogim	74		
	Total	**892**		

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Correction

Correction: Balgah et al. Impacts of Floods on Agriculture-Dependent Livelihoods in Sub-Saharan Africa: An Assessment from Multiple Geo-Ecological Zones. *Land* 2022, *12*, 334

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Text Correction

There was an error in the original publication [1]. In the sentence below (in Section 4.2.3), the word 'not' was missing, and the word 'reported' was changed to 'stated'.

A correction has been made to **Section 4.2.3**, **Paragraph 1:**

Figure 6 presents the summary of damages to private and public property across all the case studies and by geo-ecological zones. A significantly higher proportion of respondents in the Sudano-Sahelian zone stated to have not experienced property damages after floods, compared to their counterparts in the Coastal and the Western Highlands zones (94%, 23%, and 86%, respectively).

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Article

Decision Analysis of the Adaptation of Households to Extreme Floods Using an Extended Protection Motivation Framework—A Case Study from Ethiopia

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Abstract: Private extreme flood adaptation measures are cost effective and environmentally friendly. The objective of this study is to explore the major adaptation strategies, the determinants of the decisions of households to flood adaptation, specific prophylactic measures, and the constraints of these adaptation measures. A multi-stage sampling technique was employed to select the 337 samples for the study. As the data analysis showed, farm households adopted moving to high elevation places, selling cattle, seasonal migration, flood tolerant rice, planting trees, and the construction of a dike as adaptation measures to flood. The binary logistic regression results from both the socioeconomic and protection motivation theory (PMT) showed that marital status, sex, family size, off-farm income, previous flood experience, access to credit, and the average number of extension visits had a statistically significant positive influence on the flood adaptation decision of households. On the other hand, age, educational attainment, farm size, and access to extension played a negative but statistically insignificant role in flood adaptation decision. The scientific novelty of the paper is that its results revealed that not only the socioeconomic and demographic characteristics of households play a role in the decision-making reactions related to the flood, but also the psychological preparedness of the decision makers. The analysis also drew attention that, due to the mitigation of global influences, in the coming years, households can assume a much more decisive role in the process of local food supply. Therefore, in order to ensure safe supply, climate change-related measures and adaptation strategies must be defined very precisely. Dealing with this phenomenon must be part of social and business innovation as it can cause not only food supply problems but also various migration effects, which, in the short term, would result in the most serious damage to the social system.

Keywords: extreme floods; adaptation of households to flood; climate mitigation; protection motivation theory; Ethiopia; climate change

1. Introduction

Surfeit literature confirms that the economic damage that is attributed to extreme flood worldwide has been increasing exponentially since the middle of the 20th century [1]. In 2017 alone, an estimated global weather-related disaster loss amounted to more than USD 300 billion [2]. Flood and drought are responsible for 80% of disaster related deaths and 70% of the economic damages in Sub-Saharan Africa [3]. Flood hazard, one of the manifestations of climate change and variability, is even less predictable than climate change [4], whose brunt pressure has been manifested in Ethiopian highlands, which has damaged agriculture and ecosystems [5–7]. Flood can be triggered by the duration and intensity of rainfall and the nature of topography and manmade factors [7]. Studies by [5] and [8] reported that there are tendencies for the frequent occurrence and negative impacts of flooding over time. Sources also reported that the changing conditions of climate change may exacerbate the flooding pressure in Ethiopia [7].

Ethiopia is still just preparing for climate change adaptation through adaptation programs at the local level [9,10]. A number of issues constrain the country's adaptive capacity to climate change and natural hazards such as flood, including the limited livelihood diversification of farm households, heterogeneous withstanding and absorbing capacity, the low level of education of smallholder farmers, and the inefficiency of government provisions [9]. The extent of flood damage can be determined by the proactive capacity of the implemented policy, response plan, changes in land use patterns, and infrastructure strength [7].

Furthermore, Ethiopia lacks real-time hazard prediction technologies as well as the capacity to recover from disasters [10]. Flooding is having a greater impact on the poorest and most vulnerable people, implying that an appropriate combination and application of adaptation measures is unquestionably necessary [2]. Few authors, including [7], have examined the historical flood events and hydrological extremities in Ethiopia since 1950. The decade from 2001 to 2010 had five flood years, making it the most flooding decade, followed by the four-year flood period from 1991 to 2000. In addition, two flood years occurred between 2010 and 2020.

Most flooding in Ethiopia is caused by river overflow emerging from prolonged rainfall that inundates lowland plains. Fogera plain is one of the most severely flooded areas in northwest Ethiopia, in general, and the Lake Tana catchment area, in particular. The frequent floods that occurred at various times in 2006/2007 and 2018/2019 severely impacted many people by degenerating ground water and destroying roads, houses, and the education sector.

Because investment is costly in developing countries, public adaptation measures are less feasible. As a result, private household adaptation measures must be encouraged. This, however, necessitates a better understanding of the socioeconomic, demographic, and psychological factors that influence households' adaptation choices [11]. The decision of households to take flood-protection measures prevents 80% of economic damage [12]. Despite this, not all households are willing to take precautionary measures against extreme flood damage. Exploring the reasons for "prophylactic actions" in response to "noxious" natural events such as flooding is critical for both private and public decision makers to effectively offset the negative effects of flooding on socioeconomic and environmental damages [12]. We hypothesize that not only the socioeconomic and demographic characteristics of households play a role in decision-making reactions to floods but also the psychological preparedness of decision makers. We wonder whether scientific studies can elucidate the origins of this connection.

Flood adaptation, according to literature reviews, is a dynamic and uncertain issue, and we recommend that it includes the interaction and coordination of social, psychological, economic, institutional, and spatial systems in order to effectively counter-balance potential flood damage. We are interested in learning how a protection motivation model can be used to describe this relationship. Identifying the various mechanisms of extreme flood adaptation in the study area has two advantages. First, it assists in distinguishing between simple mechanisms that can be handled privately by households and mechanisms that require a large sum of investment, and in assigning responsibilities accordingly [13]. Second, it serves as a reference tool for engineering method-specific policy and strategy to address flooding challenges at the lowest possible cost, because indigenous and conventional adaptation methods are both cost effective and environmentally friendly [14]. Furthermore, understanding the specific nature of adaptation mechanisms as simple and complex, private and public, ex-ante and ex-post is required to take appropriate action based on their nature [14].

Many studies in Ethiopia emphasized farmers' choice of adaptations to climate change, including [15–26]. However, much effort is required to focus and study the elements and manifestations of climate change, such as flooding, in order to respond intelligently, as climate change adaptation takes a region-, farm-, and household-specific approach [20,21,27]. Furthermore, multi-purpose information is crucial on the most promising adaptation options available to efficiently allocate limited resources [28], as community level adaptations are the first-line preventive approaches that save from multi-dimensional damages caused by flood [13].

Using binary logistic regression, studies on flood adaptation focused on the socioeconomic and demographic characteristics of farm households as determinants of whether or not to adopt any flood adaptation strategies. Investigating the factors that influence whether or not to implement flood adaptation strategies is one thing, but examining the socioeconomic variables that influence whether or not to implement a specific adaptation measure is another. Because some of the different adaptation measures are mutually exclusive and differ in their input requirements (labor, effort, and time), investment cost, and level of potential efficacy, a household may not have the same degree (intensity) of tendency to adopt one type of precautionary measure [29]. For instance, Reference [24] found that older farmers were more likely to adopt crop diversification than younger farmers, whereas they were less likely to adopt soil conservation and temporary migration as adaptation measures. This is due to the fact that the decision to adapt to any specific measure can be influenced by a variety of socioeconomic factors [30]. As a result, we can conclude that the results of a general binary logistic regression model that estimates the relationship between determinant factors and flood adaptation decisions should not be relied on for policy orientation because they may be misleading.

Furthermore, research in Ethiopia on the determinants of household flood adaptation decisions overlooked the importance of characterizing these determinants using the protection motivation theory (PMT) framework. The protective motivation theory concept is adaptable enough to be used in a multinomial logistic regression model, and its various classes of variables can be used in a regression analysis. Because empirical results on these variables produce mixed results, the variables of the extended model are used in this study instead of the variables of the basic (traditional) model [29].

Because of its lowland and gently sloping topography, Fogera woreda is a well-known flood-affected area. This necessitates an assessment of the impact of various determinant factors on the adoption of any or a specific precautionary measure in order to effectively respond to the frequently occurring flood hazard in the study area. This is significant because adaptation intervention is not a random task and requires detailed scientific information to effectively engineer farm-specific program plans (17). Therefore, a multinomial logit model that treats the dependent variable (choice of adopting a specific adaptation measure) as having more than two responses was employed.

This study attempted to articulate the various flood adaptation approaches and socioeconomic determinants of farm households' decision to adopt or not adopt any method. Furthermore, the paper investigated the socioeconomic-economic-psychological-institutional variables that determine specific flood adaptation measures, as well as the potential barriers that prevent farm households from adopting any measure to live with flooding events without being significantly impacted. The following sub-questions were addressed in the study: (1) What are the main preventive measures for extreme flooding in the study area? (2) Do socioeconomic-economic-psychological-institutional variables have the same effect on the decision to implement any flood-prevention measure and a specific adaptation measure? (3) What are the major flood adaptation constraints in the study area?

There are numerous contributions of the study. First, it identifies the adaptation measures that are most commonly used in the study area. Second, it promotes understanding of the various ways of characterizing the various flood-prevention (adaptation) measures. Third, it contributes to the growth of literature on the empirical study of socioeconomic-psychological and institutional factors influencing flood adaptation decisions. Fourth, the study makes significant contributions to the framing of methodological approaches to flood adaptation research by clearly commenting on the nature, advantages, and limitations of each method. Fifth, it can be used as a stepping stone for researchers as well as an input for policy makers and stakeholders in flood risk management.

2. Literature Review

Humans will either mitigate or adapt to any natural or environmental threats, such as flooding. Mitigation strategies are short-term solutions that provide an instant fix to a problem that disrupts lives and causes property damage. The permanent courses of action that help communities cope with flooding dangers are known as adaptation methods. Additionally, adaptation is described as a response to or preparation for a climate change or flood threat that has already occurred or is predicted. [31]. In flood-prone areas, household level flood adaptations are essential instruments for reducing the negative effects of floods. [32,33].

Adaptation measures, however, have different characteristics. They can be classified as private and public (on the basis of ownership), simple and complex (on the basis of investment), ex-ante and ex-post or precautionary and reactive (on the basis of timing and purpose), hard and soft, and autonomous and planned adaptations. Adaptations can also be classified on the basis of timing (short term coping strategies and long-term adaptation strategies), reasons of implementation and spontaneity. On the basis of timing, short-term coping strategies and long-term adaptation strategies can be differentiated [30]. Autonomous adaptations are taken by individuals or households while planned adaptations, on the other hand, are taken by governments, but they may sometimes hinder autonomous adaptation when individuals wait for government provisions [34]. Due to the involvement of several stakeholders in technical, institutional, social, economic, and psychological issues, decision-making about flood dangers is complex. [29].

The empirical methods that have tried to characterize the determinants of flood adaptation can be grouped in three main classes: the socioeconomic model, the protection motivation theory (PMT), and coupled agent-based model (ABM). The socioeconomic model states that the social, economic, and demographic characteristics of households, such as age, sex, education status, marital status, income, family size, and farm size, determine their adaptation decisions to private prophylactic measures to flood incidences. However, it is limited in power to better explain the adaptation decision of households since it presumes adaptation decision as a matter of material welfare. Protection motivation theory (PMT) was first applied in psychology, and it is attributed to Rogers, who developed it in 1975 [35]. Its flexibility allowed it to be adopted in the study of the reasons why individuals adopted or not any measure against any natural hazards such as flooding. The first application of the theory in adaptation decision was made by [12]. The greatest strength of the protection motivation theory was its capacity to combine the variables of the socioeconomic model and psychological variables together. Above all, it assumes that adaptation decision is a matter of behavioral change and this, in turn, depends on individuals' psychological conditions [12]. The theory also assumes that the role of socioeconomic conditions of individuals is not to directly enable adaptation decisions but to result in the behavioral change of individuals to take adaptation measures. The theory, therefore, has now two elements in it: the traditional (basic) model and the extended version [29]. The following figure (Figure 1) shows how the entity of the PMT model is enlarged.

The traditional components of the protection motivation theory are threat appraisal, which indicates whether an individual thinks the threat of flooding is high (measured by perceived likelihood of the hazard occurring, perceived severity of damage, and fear), and coping appraisal, which indicates whether an individual thinks his ability to deal with the issue is strong enough (proxied by protective response efficacy, perceived self-efficacy and protective response costs). The expanded version also covers socioeconomic and demographic factors (age, sex, educational status, marital status, off-farm income, and family size) as well as psychological factors (prior flood experience, perception of flood danger, and terror). The PMT model could yet be expanded to incorporate more explanatory factors, such as institutional variables (access to credit and extension) and farm characteristics (farm size).

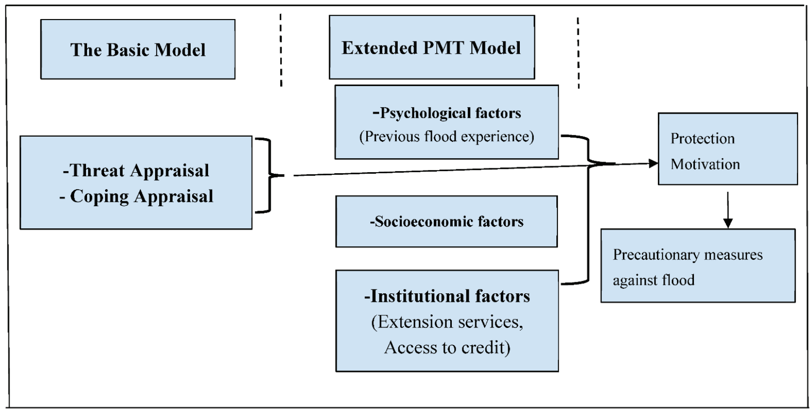

Figure 1. Protection motivation theory (Authors' own edition based on Twerefou [29]).

The coupled agent-based model (CABM) is a computational model that integrates the interaction of agents—both autonomous and heterogeneous—and their environment—flood—through controlled simulations to examine the contribution of agents' behavior and socioeconomic-institutional characteristics to people's decisions about how to adapt to flood incidence [32].

In the literature, many adaptation mechanisms have been identified across many countries. For instance, in Pakistan, References [36,37] identified that farmers used adaptation options, including elevated ground floor, crop variety, shifting sowing seasons, and maintaining food stock such as wheat. A study by [38] also reported that farmers in Ghana used sandbags, raising the foundations of their buildings, trampoline, creating pathways for flood waters, livelihood diversification, and crop varieties. In Indonesian Jakarta, raising the housing level, building terraced housing, and building small dikes were identified [39]. Furthermore, Reference [40] on households' adaptation mechanisms to flood risk, Kenya reported moving family and valuable goods to safe places, constructing flood diversion trenches, and seeking relief from government and other agencies as the main coping ways. In China, stream recovery, green levees, raised and floatable structures, ground detentions, rooftop detentions, and reservoirs were identified as landscape adaptations to flooding by [41].

In Ethiopia, Dera woreda of South Gondar zone, Reference [24] informed that farmers used crop diversification, temporary migration, and soil and water conservation as adaptation measures. In Bangladesh, Reference [42] identified money borrowing, reducing consumption, migration, and receiving grants from external donors as coping mechanisms to unprecedented flood events and land-use zoning and embankments [4]. Landscape design was listed as flood adaptation in China [41]. In Namibia, Reference [30] identified gardening and selling poles, firewood, collecting wild food, and receiving food aid as short-term adaptation methods. Furthermore, selling reeds, firewood and thatching grass, charcoal production, and wild food collection for sale were identified as immediate solutions in Zambia. Long-term adaptation strategies include cattle trade, harvesting flood water, changing planting dates, applying conservation agriculture, and fish farming in Namibia, while in Zambia, conservation agriculture, acquiring preparedness skills, harvesting of flood water, and practicing flood proofing were major adaptation methods [30]. In the Bengal state of India, households were found to be used to borrowing money, selling assets and livestock, diversification of livelihoods, migration, elevating the height of their houses, and preserving food and fuel stocks [43]. Similarly, [34], in Ghana Dome, various feasible adaptation mechanisms were applied.

So far, several empirical studies have been conducted on the connection between flood adaptation decision and its determinant factors at varied regional scales and produced heterogeneous results. For instance, these studies include: in India [44,45]; in Ethiopia [46]; in Ghana [47]; in France [48]; in Pakistan [49]; in Bengal [43]; in Namibia and Zambia [30] and in Bangladesh [42]; to mention some. On the influence of previous flood experience, References [42,50] found that farmers' perception of hazards and damage from previous experience is an important deriver for flood adaptation. Similarly, Reference [47] found that access to extension, farm size, and information on flood occurrence have positive derives on the adaptation decision of households in Ghana. Access to credit, education level, and farm size were found to have influenced adaptation decision positively [51,52].

A multinomial logit model result discovered that age and education level are significant derivers for adaptation decision. Similarly, [24] the same model found that male headed households, family size, age, and access to extension promote adaptation decisions. In addition, the administrative system of nations was found to hinder or promote adaptive capacities to flood risk [53]. What is more, Reference [30], in their comparative study in Namibia and Zambia, reported that age, land size, length of stay in the flood plain, the duration of floods, and marital status positively influenced the long-term adaptation decisions to flood incidences. On the other hand, Reference [47] also found that age, education, and access to credit have a negative influence on the adaptation decision of households in Ghana. Farm size was negatively correlated with migration as an adaptation strategy [24].

3. Data and Methods

The absolute geographical location of Fogera woreda is between 11°57′ and 12°30′ N and 37°35′ E–37°58′ E. The woreda is one of the woredas in South Gondar Zone, Amhara regional state. It covers an area of 117,414.02 km^2 and is subdivided into 33 rural and two urban Kebele administrations. It has a total population of 226,595 (115,693 men and 110,902 women), of which 201,411 (88.89%) are rural and 25,184 (11.1%) are urban dwellers. The total area of the woreda is about 117,414.02 square kilometer with a crude population density of 206 persons per square kilometer. The study area is flat and prone to flooding. The woreda is dominated by flat land (76%), while the mountain slopes and rugged terrain account for 24%. The agro-climatic zone of the woreda is classified as woina-dega (1501–2500 masl). Total annual rainfall ranges from 1103 mm to 2400 mm/year. The mean annual rainfall is 1751.5 mm, and mean monthly values vary between 0.6 mm (January) and 415.8 mm (July). Mixed farming characterizes the woreda mainly. Figure 2 below shows the map of the study area.

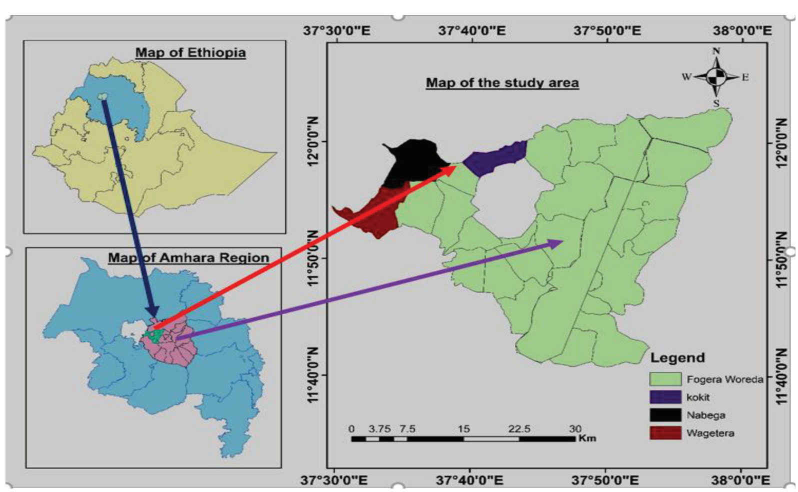

Figure 2. Location Map of the Study Area.

3.1. Sample Size and Sampling Technique

The sampling technique employed in this study was a multi-stage sampling. First, Fogera woreda was selected purposively because of its severe flood experience. Second, three kebeles (Nabega, Wagetera, and Kokit) were selected randomly from 33 kebeles (counties) of the woreda, as the areas were equally prone to flooding. Third, a total of 337 samples were taken randomly and proportionally. The three kebeles have a total of 2130 households. The total sample size was determined following Yamane's (1967) formula, which is expressed as follows:

$$\mathrm{n} = \frac{\mathrm{N}}{1 + \mathrm{N}(\mathrm{e}^2)}$$

where n is the sample size, N is the total household size, and e is the level of precision, which is 5%. Therefore, the sample size is determined as:

$$\mathrm{n} = \frac{\mathrm{N}}{1 + \mathrm{N}(\mathrm{e}^2)} = \frac{2130}{1 + 2130(0.05^2)} = 336.76 \cong 337$$

3.2. Data Type and Data Collection Methods

Primary cross-sectional data were gathered through questionnaire, key informant interview, and focus group discussion. Specifically, data were collected on socioeconomic and demographic variables (age, sex, educational status, marital status, off-farm income, farm size, and family size), psychological variables (previous flood experience), and institutional variables (access to credit, access to extension, and average number of extension visits per year) through structured questionnaire. In addition, data on the major adaptation strategies and constraints were obtained through key informant interviews and focus group discussions for the purpose of strengthening and complementing questionnaire data.

3.3. Methods of Data Analysis

Data were analyzed through descriptive statistics and logistic regression model using STATA15. The descriptive statistics helped to describe the existing socioeconomic conditions of the study area. The continuous socioeconomic conditions of the farm households were described in terms of mean, standard deviation, and minimum and maximum values. The categorical variables were presented in percentage. Two binary logit models were run to examine the determinants of the flood adaptation decision of households considering two model frameworks: the socioeconomic and the extended model. The multinomial logistic regression model was used to examine the main socioeconomic-psychological-institutional variables that determine household decision to adopt any adaptation measure and a specific measure employing the socioeconomic and extended PMT model for short-term and long-term adaptation strategies.

3.4. The Empirical Model: Logistic Regression Model

The logit model is used when the dependent variable is qualitative and takes more than one response value [54]. In this study, the relationship between the socioeconomic-psychological-institutional variables that affect household probability of deciding on flood adaptation measures were captured by the binary logit model. The logit model can be specified as:

$$\begin{aligned} P(y = 1|xi) &= f(\alpha o + \beta 1X1 + \beta 2X2 + \ldots + \beta mXm) \\ &= f(\alpha o + x\beta) \end{aligned} \quad (1)$$

where, p is the probability that a household decides to adopt any flood adaptation measure; y is the adoption decision of households and takes the value 1 if a household adopted at least one measure, or takes the value *0* if it did not adopt any; x_1, x_2, … x_n are explanatory socioeconomic-psychological-institutional variables that affect the probability of adoption.

The log of odds at which households would be more likely to adopt any adaptation measure is expressed as the ratio of the probability to adopt or to not to adopt at all as follows.

$$\log\left(\frac{p}{1-p}\right) = \frac{e^{\alpha o+\beta 1X1+\beta 2X2+\ldots+\beta mXm}}{1+e^{\alpha o+\beta 1X1+\beta 2X2+\ldots+\beta mXm}} \quad (2)$$

On the other side, the likelihood that a household will choose to use a certain adaptation measure can be expressed in the same way as the above, with the difference that the dependent variable is now the household's choice to adopt a particular adaptation measure. The use of "flood tolerant rice," "moving to high elevation sites," "selling cattle," "planting trees," "building of a dike," and "seasonal migration to safe regions" are some of the primary adaptation techniques in the research area. These responses can be divided into two categories: long-term adaptation strategies and short-term coping strategies. To put it simply, in the research region, short-term coping strategies include moving to high elevation locations, selling cattle, and seasonal migration to safe places, whereas long-term coping strategies include planting trees, cultivating flood-tolerant rice, and building dikes. To calculate the likelihood that short-term and long-term measures will be adopted, multinomial logit models were used. On the basis of the multinomial logit model, the relationship between short-term coping mechanisms and the factors that influence the likelihood that they may adapt can be modeled as shown below

$$P(y=1|xi) = f(\alpha o+\beta 1X1+\beta 2X2+\ldots+\beta mXm) \quad (3)$$

where p is probability,

$$y = \begin{cases} 1,\ if\ a\ household\ adopted\ moving\ to\ high\ elevation\ places \\ 0,\ otherwise \\ 1,\ if\ a\ household\ adopted\ selling\ cattle \\ 0,\ otherwise \\ 1,\ if\ a\ household\ adopted\ seasonal\ migration\ to\ safe\ places \\ 0,\ otherwise \end{cases}$$

X's are socioeconomic-psychological-institutional variables, and β's are coefficients of explanatory variables. Similarly, the relationship between long-term adaptation methods and the determinants of the probability of adapting to them can be analyzed on the basis of the multinomial logit model as above.

3.5. Description of Variables

The following table (Table 1) presents the list of socioeconomic-psychological-institutional variables, description, expected sign, and scientific literature sources.

Table 1. Description and Operational Definition of Variables.

Variables		Description	Expected Sign	Literature Sources
Socioeconomic variables	Age	Age of a household head	±	[37,47,52]
	Sex	Dummy (1 = Male, 0 = Female)	+	[42,50]
	Education status	Dummy (1 = Literate, 0 = Illiterate)	±	[29,52]
	Marital status	Dummy (1 = Married, 0 = Otherwise)	+	[55,56]
	Family size	No. of family members in a household	+	[24]
	Farm size	Size of farmland in ha.	+	[30]
	Off-farm income	Dummy (1 = Yes, 0 = No)	+	[15]
Psychological variables	Previous Flood Experiences	Dummy (1 = Yes, 0 = No)	+	[47]
Institutional variables	Credit access	Dummy (1 = Yes, 0 = No)	+	[51]
	Access to extension	Dummy (1 = Yes, 0 = No)	+	[47]
	No. of contacts per year	Average no. of extension contacts per year	+	[51]

Source: Authors' own compilation based on literature, July 2022.

4. Results

4.1. Descriptive Statistics of Continuous Variables

Continuous variables were summarized using mean, standard deviation, and minimum and maximum values (Table 2)

Table 2. Basic Descriptive Statistics of Continuous Variables.

Variables	Observation	Mean	Std. Dev.	Min	Max
Age	337	44.13353	9.72616	18	72
FamSize	337	6.14	2.22	1	12
FarmSize	337	1.2	1.8	0	3
AvrNuVisits	337	1.76	1.76	0	12

Source: Household Survey, May 2022.

The mean age of household heads in the study area is 44 years (Table 2), which implies that household heads are, on average, in their productive working age range. The average family size (FamSize) is approximately 6 people per household, with a household having just one person and with households having 12 people. The mean farm size (FarmSize) in hectare is approximately 1 hectare, indicating that households in the study are smallholder farmers. The average number of extension visits (AvrNuVisits) is approximately 2 times a year.

4.2. Descriptive Statistics of Dummy Variables

Categorical variables are e presented in a tabular form for better understanding. Thus, Table 3 presents the categorical variables used in the study in percentages.

Table 3. Basic Descriptive Analysis of Dummy variables.

Variables		Freq	Percent
Sex	Male	272	80.7
	Female	65	19.3
Marital Status	Married	302	89.6
	Otherwise	35	10.4
Education Status	Literate	172	50.7
	Illiterate	165	49.3
Off-farm income	Yes	63	18.7
	No	274	81.3
Flood Adaptation	Yes	235	69.7
	No	102	30.3
Prev.Flood Exp.	Yes	185	54.9
	No	152	45.1
Access to Credit	Yes	96	28.5
	No	241	71.5
Access to Extension	Yes	198	58.8
	No	139	41.2

Source: Household Survey, May 2022.

As Table 3 above presents, 80% of the households were male-headed whereas the remaining 20% were female-headed families. Nearly 90% of household heads were married whereas just 51% were literate. Only 19% of households had off-farm income. Furthermore, approximately 71% of households reported that they adopted at least one flood adaptation measure. Additionally, 55% of households reported that they had previous flood experience in the last 5 years. The statistical figures also informed that only 28% of households had access to credit services. In addition, nearly 59% households received access to extension services. From the statistical figures, it can be concluded that institutional facilities such as credit access, extension access, education, and training are weakly available in these communities.

4.3. Flood Adaptation Strategies in Fogera Woreda

Household heads were prompted about their adaptation mechanisms to the frequent extreme flood incidence. They reported that they either used the combination of measures or sometimes just one measure. One way to reduce the agricultural damage of flooding was to plant a flood-tolerant rice variety on their farms (66%). They also shifted their movable assets and properties and families to high elevation places (63.5%) until the inundation level decreases. Where the flood incidences were high, households took temporary migration (24.63%) to safe places as an alternative method. In addition, households also reported selling cattle (41.5%), planting trees (39%), and the construction of a dike (24%) as flood adaptation measures. Figure 3 below shows the major adaptation strategies and the percentage distribution use by households.

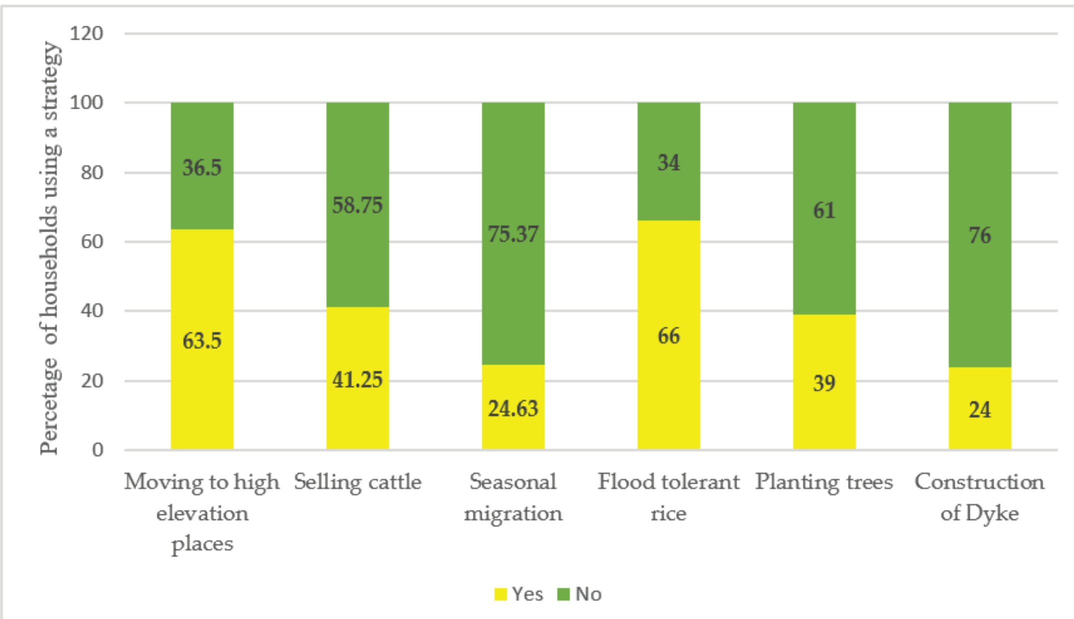

Figure 3. The Common Adaptation Strategies in the Study Area. Source: Household Survey, May 2022.

4.4. Results of Logistic Regression Analysis

Examining whether or not the socioeconomic-psychological-institutional variables have the same influence on household decisions to adopt any adaptation measure and a specific measure was one of the objectives of this study. Furthermore, the adaptation strategies used by households (70% of them) were categorized into short-term coping mechanisms and long-term adaptation strategies. To that end, separate multinomial logit models were run for the short-term and long-term adaptation strategies together with comparing the results of the socioeconomic model and the extended PMT model. According to the socioeconomic model, the socioeconomic and demographic characteristics of farm households determine their likelihood to take any flood adaptation measure. This study goes beyond this and tests whether these socioeconomic characteristics have the same influence on both the decision to take any measure and a specific short-term measure. Table 4 below presents the binary (for flood adaptation decision, see column A) and multinomial (for short-term coping mechanisms: moving to high elevation places, selling cattle, and seasonal migration, see columns B, C, and D) logistic regression results.

Table 4. Regression Results of the Socioeconomic Model (Short-term coping methods).

Flood Adaptation Decision (A)				Moving to High Elevation Places (B)			Selling Cattle (C)			Seasonal Migration (D)		
Variables	**Coef.**	**OR**	***p*-Value**	**Coef.**	**OR**	***p*-Value**	**Coef.**	**OR**	***p*-Value**	**Coef.**	**OR**	***p*-Value**
Age	−0.06	0.94	0.000 ***	−0.048	0.95	0.001 ***	−0.028	0.97	0.044 **	−0.077	0.92	0.000 ***
Sex	0.06	1.06	0.867	−0.39	0.67	0.285	−0.388	0.67	0.239	0.181	1.19	0.614
EduStatus	−0.142	0.86	0.360	−0.02	0.97	0.884	−0.114	0.89	0.412	−0.160	0.85	0.301
MariStatus	0.53	1.71	0.022 **	0.55	1.74	0.014 **	−0.352	0.7	0.074 *	−0.002	0.99	0.989
FamSize	0.29	1.34	0.000 ***	0.25	1.28	0.000 ***	0.153	1.16	0.009 ***	0.155	1.16	0.029 **
OffFarmInc	0.42	1.53	0.001 ***	0.23	1.27	0.003 ***	0.303	1.35	0.000 ***	0.004	0.99	0.942
FarmSize	−0.068	0.93	0.388	−0.01	0.98	0.797	0.04	1.04	0.538	0.047	1.048	0.520
_cons	1.32	3.77	0.119	0.77	2.17	0.331	0.36	1.14	0.631	1.038	2.282	0.211
LR chi2(7)	60.86			49.27			39.13			23.01		
Prob > chi2	0.000			0.000			0.000			0.001		
Pseudo R2	0.147			0.111			0.085			0.061		
N	337			337			337			337		

Source: Household Survey, May 2022. [Note: Coef = coefficient; OR = Odds Ratio; LR chi2 = Likelihood ratio chi-square test; Prob = probability]. *** $p < 1\%$, ** $p < 5\%$, * $p < 10\%$.

As Table 4 depicts, the decision of the households to take any flood adaptation measure was significantly determined by the age, marital status (Odds Ratio = OR = 1.71), family size of the household head (OR = 1.34), and off-farm income (OR = 1.53), with age (OR = 0.94) having negative influence (column A). Interestingly, age has consistent negative influence on the household choice of specific short-term coping mechanisms (columns B, C, and D) although at varied significance levels. In addition, family size and off-farm income have consistent positive influence on the choice of specific short-term coping methods. However, marital status of a household head had heterogeneous influence. While it had a significantly positive influence on the adoption of "moving to high elevation places", it negatively influenced the adoption of "selling cattle" and "seasonal migration" as short-term coping methods.

Furthermore, the determinants of household decision to adopt a specific long-term method were also examined. Table 5 below presents the regression results of the binary (column A) and multinomial logistic models (columns B, C, and D). The choice of the adoption of long-term adaptation methods were regressed on the socioeconomic characteristics of households.

Table 5. Regression Results of the Socioeconomic Model (Long-term Adaptation methods).

Flood Adaptation Decision (A)				Flood Tolerant Rice (B)			Planting Trees (C)			Construction of Dyke (D)		
Variables	**Coef.**	**OR**	***p*-Value**	**Coef.**	**OR**	***p*-Value**	**Coef.**	**OR**	***p*-Value**	**Coef.**	**OR**	***p*-Value**
Age	−0.06	0.94	0.000 ***	−0.052	0.94	0.000 ***	0.001	1.00	0.965	−0.047	0.953	0.004 ***
Sex	0.06	1.06	0.867	−0.325	0.72	0.380	0.299	1.34	0.376	0.210	1.233	0.573
EduStatus	−0.142	0.86	0.360	−0.093	0.91	0.526	−0.003	0.99	0.980	−0.276	0.758	0.075 *
MariStatus	0.53	1.71	0.022 **	−0.297	1.34	0.140	0.137	1.14	0.427	−0.297	0.742	0.231
FamSize	0.29	1.34	0.000 ***	−0.216	1.24	0.000 ***	0.199	1.22	0.001 ***	0.100	1.105	0.140
OffFarmInc	0.42	1.53	0.001 ***	0.260	1.29	0.003 ***	0.241	1.27	0.000 ***	0.076	1.079	0.235
FarmSize	−0.068	0.93	0.388	0.012	1.01	0.860	−0.127	0.88	0.065 *	−0.042	0.958	0.571
_cons	1.32	3.77	0.119	1.49	4.45	0.064 *	−1.73	0.17	0.023 **	0.901	2.463	0.287
LR chi2(7)	60.86			42.37			30.25			15.83		
Prob > chi2	0.000			0.000			0.000			0.026		
Pseudo R2	0.147			0.098			0.067			0.042		
N	337			337			337			337		

Source: Household Survey, May 2022. *** $p < 1\%$, ** $p < 5\%$, * $p < 10\%$.

As Table 5 above clearly shows, age has heterogeneous influence on the adoption of long-term adaptation strategies (see columns A, B, C, and D); while it negatively and significantly influenced the adoption of both "flood tolerant rice" and "construction of a dike", it promoted "planting trees" as a long-term adaptation option, although it was not statistically significant. Marital status also had heterogeneous influence. It positively and statistically significantly influenced flood adaptation decision. However, its influence on the adoption of long-term adaptation strategies is insignificant, although at different causation direction. Family size influenced the adoption of flood tolerant rice negatively and statistically significantly, whereas it had a statistically significant influence on the planting of trees. Interestingly, off-farm income was the only consistent variable. It positively influenced flood adaptation decision and the adoption of both flood tolerant rice and planting trees.

The other regression was run on the influences of the socioeconomic-psychological-institutional variables on flood adaptation decision and short-term coping methods, which is based on the extended protection motivation theory (PMT). Table 6 shows the regression results of both the binary (for flood adaptation decision (column A)) and multinomial (short-term coping methods (columns B, C, and D)) logistic regression results.

Table 6. Regression Results of the Extended PMT Model (Short-Term Coping Methods).

Flood Adaptation Decision (A)				Moving to High Elevation Places (B)			Selling Cattle (C)			Seasonal Migration (D)		
Variables	**Coef.**	**OR**	***p*-Value**	**Coef.**	**OR**	***p*-Value**	**Coef.**	**OR**	***p*-Value**	**Coef.**	**OR**	***p*-Value**
Age	−0.053	0.94	0.011 **	−0.036	0.96	0.036 **	−0.016	0.98	0.291	−0.069	0.93	0.001 ***
Sex	0.363	1.43	0.525	−0.414	0.66	0.358	−0.261	0.76	0.463	0.356	1.42	0.364
EduStatus	−0.393	0.67	0.094 *	−0.060	0.94	0.745	−0.164	0.84	0.285	−0.187	0.828	0.266
MariStatus	0.653	1.92	0.034 **	0.610	1.84	0.020 **	−0.380	0.68	0.076 *	−0.012	0.987	0.955
FamSize	0.132	1.14	0.123	0.125	1.13	0.103	0.087	1.09	0.20	0.088	1.09	0.30
OffFarmInc	0.400	1.49	0.007 ***	0.195	1.21	0.039 **	0.279	1.32	0.000 ***	−0.039	0.96	0.586
FarmSize	−0.058	0.94	0.592	−0.014	0.98	0.872	0.037	1.03	0.605	0.033	1.03	0.684
Prev.Fl.Exp	3.962	52.6	0.000 ***	2.545	12.75	0.000 ***	1.078	2.93	0.000 ***	1.95	7.04	0.000 ***
AccessCredit	1.31	3.72	0.004 ***	1.023	2.78	0.005 ***	0.566	1.76	0.041 **	0.183	1.20	0.55
AcExtension	−0.639	0.52	0.404	−0.326	0.72	0.55	1.03	2.82	0.012 **	0.779	2.18	0.100
AvrNuVisits	0.587	1.80	0.019 **	0.345	1.41	0.038 **	−0.014	0.98	0.896	−0.012	0.98	0.918
_cons	−0.320	0.72	0.785	−0.795	0.45	0.42	−1.16	0.31	0.173	−0.774	0.46	0.427
LR chi2(7)	222.48			164.9			88.8			76.66		
Prob > chi2	0.000			0.000			0.000			0.000		
Pseudo R2	0.538			0.373			0.194			0.20		
N	337			337			337			337		

Source: Household Survey, May 2022. *** $p < 1\%$, ** $p < 5\%$, * $p < 10\%$.

Table 6 presents clearly that age has consistent influence on flood adaptation decision, as well as on the choice of specific short-term measures, despite the fact that this is at different significance levels. This tells us that older people are less likely to take any adaptation measure (note that all ORs < 1), including moving to high elevation places, selling cattle, and seasonal migration. The education status of household heads influences flood adaptation decision and the choice of specific measure negatively, although it is not statistically significant. Marital status positively and significantly triggered flood adaptation decision and "moving to high elevation places" at the same time. However, it restricted the adoption of "selling cattle" and "seasonal migration" as short-term coping mechanism. In the extended PMT model, surprisingly, there is no evidence that family size has anything to do with adaptation decision as well as short-term coping methods. In this regression, households who had off-farm income option were more likely to take flood adaptation measures than those who did not. This also allowed households to adopt "moving to high elevation places" and "selling their cattle", whereas it had influence on "seasonal migration."

One can clearly witness that psychological and institutional variables have statistically significant influence on flood adaptation decision and the choice of specific measures; psychology and institutions do play a role. To be more specific, households with previous flood experience were more likely to adopt the three short-term coping methods. Access to credit also played a crucial role in changing the decision-making behaviors of households in the study area. Furthermore, access to extension influenced households to sell their cattle, although the average number of extension visits has a negative insignificant influence on this measure. It can be seen that the average number of extension visits had a significantly positive effect on household decision to take adaptation measure together with "moving to high elevation places" as a specific coping mechanism. In this regression result sex, family size, and farm size were insignificant. Table 7 below clearly presents the regression results of the extended PMT model on flood adaptation decision (column A) and on the long-term adaptation strategies (column B, C, and D).

Table 7. Regression Results of the Extended PMT model (Long-Term Adaptation Strategies).

Flood Adaptation Decision (A)				Flood Tolerant Rice (B)			Planting Trees (C)			Construction of a Dike (D)		
Variables	**Coef.**	**OR**	***p*-Value**	**Coef.**	**OR**	***p*-Value**	**Coef.**	**OR**	***p*-Value**	**Coef.**	**OR**	***p*-Value**
Age	−0.053	0.94	0.011 **	−0.045	0.955	0.017 **	0.012	1.01	0.412	−0.034	0.965	0.057 *
Sex	0.363	1.43	0.525	−0.354	0.701	0.489	0.405	1.50	0.254	0.303	1.35	0.447
EduStatus	−0.393	0.67	0.094 *	−0.230	0.793	0.27	−0.0181	0.98	0.903	−0.306	0.735	0.066 *
MariStatus	0.653	1.92	0.034 **	0.240	1.272	0.367	0.102	1.10	0.573	−0.298	0.742	0.249
FamSize	0.132	1.14	0.123	0.0224	1.022	0.789	0.134	1.14	0.038 **	−0.000	0.99	0.994
OffFarmInc	0.400	1.49	0.007 ***	0.203	1.225	0.054 *	0.217	1.24	0.001 ***	0.027	1.02	0.691
FarmSize	−0.058	0.94	0.592	0.066	1.068	0.50	−0.145	0.864	0.05 **	−0.049	0.95	0.553
Prev.Fl.Exp	3.962	52.6	0.000 ***	3.48	32.75	0.000 ***	1.260	3.52	0.000 ***	1.43	4.18	0.000 ***
AccessCredit	1.31	3.72	0.004 ***	0.979	2.66	0.017 **	0.249	1.28	0.367	−0.328	0.719	0.299
AcExtension	−0.639	0.52	0.404	0.012	1.012	0.984	−0.525	0.591	0.225	0.897	2.24	0.057 *
AvrNuVisits	0.587	1.80	0.019 **	0.382	1.465	0.056 *	0.283	1.32	0.014 **	0.100	1.10	0.382
_cons	−0.320	0.72	0.785	0.186	1.205	0.866	−2.786	0.062	0.001 ***	−0.655	0.519	0.499
LR chi2(7)	222.4			205.6			67.40			61.22		
Prob > chi2	0.000			0.000			0.000			0.000		
Pseudo R2	0.538			0.477			0.150			0.165		
N	337			337			337			337		

Source: Household Survey, May 2022. *** $p < 1\%$, ** $p < 5\%$, * $p < 10\%$.

Regression results presented by Table 7 above shows that older household heads are less likely to adopt flood tolerant rice and construction of a dike as long-term adaptation strategies (see columns B and D). However, as the age of a household head increases by one year, it induces farm households to plant trees, although it is not statistically significant. The results also showed that literate household heads were less likely to take any adaptation measure (OR < 1). Marital status positively influenced flood adaptation decision but not for any long-term adaptation measures. The size of the household promoted planting of trees. Similarly, off-farm income availability induced the adoption of flood tolerant rice and planting of trees.

However, farm size significantly and negatively influences planting of trees as long-term adaptation method. Furthermore, the psychological effect of exposure to previous flood incidence has an important implication. It positively and statistically significantly triggered the adoption of long-term adaptation strategies. Households with credit access were more likely to adopt flood tolerant rice and planting trees. Access to extension service promoted the construction of a dike. On the other hand, the average number of extension visits had a statistically significant positive influence on the adoption of flood tolerant rice and planting of trees. In this regression result, as well, education status negatively determines long-term adaptation strategies.

4.5. Constraints to Flood Adaptation in Fogera Woreda

Identifying the major constraints to flood adaptation in the study area was one of the objectives of this study. The respondents who reported that they had not used any flood adaptation method to offset the negative effects of flooding mentioned major barriers that restricted them not to adapt to flood hazard. Figure 4 below presents these major barriers and the corresponding percentage distribution.

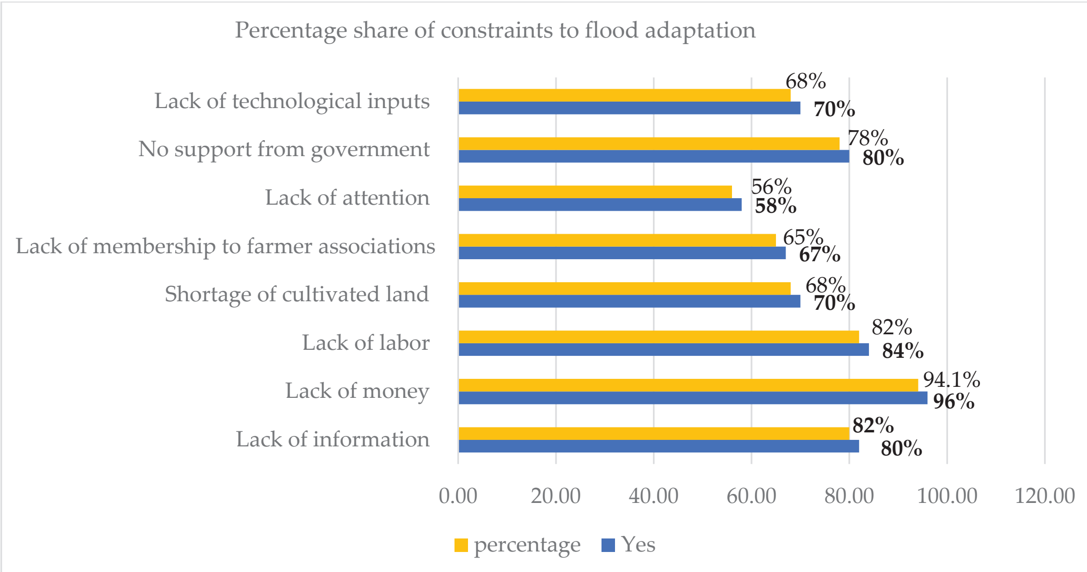

Figure 4. Major Constraints to Flood Adaptation in the Study Area. Source: Household Survey, May 2022.

As it is clear from Figure 2 above, non-adopting respondents reported that lack of money (94.1%), lack of labor (82%), lack of information (80%), lack of support from government (78%), shortage of cultivated land (68%), lack of technological inputs (68%), lack of membership to farmer associations (65%), and lack of attention (56%) were the major constraints that hold them back from adapting to flood hazards. Since the constraints are critical issues to tackle the negative effects of flooding on the socioeconomic conditions of households, stakeholders should not overlook the role of these variables in their endeavor to flood mitigation and adaptation.

5. Discussion

In both the socioeconomic and extended PMT models, the age coefficient is negative and statistically significant, with the exception of its positive but insignificant influence on the adoption of "planting trees" (See Tables 5 and 7). This means that as a farmer ages, he becomes less likely to experiment with new agricultural technologies and procedures. Young farmers, on the other hand, are curious and eager to test out new technology in the goal of increasing the return on their agricultural investment. Furthermore, younger farmers are more willing to take risks than older farmers. This is due to the ability to transform losses into revenues as people live longer lives. Time gives young farmers more flexibility in decision making. This finding is supported by the results of [47] who reported that young farmers are more curious to try on new technologies to increase their productivity, and [37] who found that younger farmers are more likely to adapt to flood events. Furthermore, older farmers are less informed of recent breakthroughs in new technology and are more hesitant to use them. To summarize, growing older is connected with decreased physical capacity, a worse likelihood of obtaining credit, limited mobility to new locations, and less demand in the work market [42]. On the other hand, age was found to determine adaptation decision positively [52]. This is due to the fact that the older the farmer, the more farming experience and opportunity the farmer has to become acquainted with the significance of various adaptation mechanisms.

In this study, it was hypothesized that the gender of the household head would have a favorable influence on flood adaptation decisions as well as specific short-term and long-term adaptation techniques. Male-headed families were expected to be more likely to take any adaptation strategy than female-headed households. However, it was found to have a heterogeneous but statistically insignificant effect both in the socioeconomic and PMT model in the study area. This suggests that there is no evidence that men and women have different chances of adapting. However, gender analysis by [50] confirmed that men and women played different roles, with women being less likely to adapt to floods. The reason for this is that women are more prone to health risks, sexual harassment, and increased responsibilities.

The protective motivation theory can explain the negative coefficient of educational status for literate household heads. Individuals (households), according to this idea, tend to respond to any threat (even flood) if two conditions are met: the hazard is perceived higher risk, and their capacity to handle the hazard is greater [29]. As a result, even if the individual is well aware of the potential threat from the hazard as a result of being educated and able to use information, the household may ignore the threat (decide not to adopt any strategy) if one of the conditions is missed, particularly due to barriers such as money and the cost of adaptation.

The marital status variable was also predicted to have a favorable impact on flood adaptation decisions and specific measures. As expected, it influenced adaptation decision positively; however, it resulted in heterogeneous results on specific adaptation strategies. It had a consistent influence on short-term coping mechanisms in both the socioeconomic and the extended PMT model. While it promoted "moving to high elevation places" it discouraged cattle selling and seasonal migration. However, as it had a negative influence on flood tolerant rice in the socioeconomic model, it had a positive influence in the extended PMT model framework. It had consistent effects on both tree planting (positive) and the construction of a dike (negative) in the two model frameworks. This finding supports the view that households do not have the same tendency to adopt specific adaptation measures as these measures vary in cost, time, effort, and input requirement [29].

Married household heads have a higher social and economic position and are hence less vulnerable to flooding damage. Short-term coping methods are more common in bigger family households. However, they had different influence on long-term adaptation strategies while only on planting trees had consistent influence. It negatively influenced the use of flood tolerant rice in the socioeconomic model, but it also positively influenced the adoption of the same method in the extended PMT model. This could be explained by the addition of psychological and institutional elements to the PMT model. It was expected that household size had a favorable influence on flood adaption decisions because larger families have more labor available for farm work [19,56].

Off-farm income opportunities to households are important since it allows them to engage in activities that are less prone to climate change and therefore to flooding damage, which further motivates individuals to take prophylactic measures. A study in Ghana by [38] also found that households who had alternative sources of income were more likely to adopt protective measures to reduce flood risk. This is because, if the livelihood system of households is fragile, they utilize every resource for daily consumption, not for investments on adaptation measures. In this study, off-farm income was a positive determinant of flood adaptation decision and to any short-term and long-term adaptation measure, except seasonal migration. Since an off-farm income option allows flexibility in decision making and protects from severe damage from flooding, households are less likely to make seasonal migration, as they can tackle the problem while staying in their original residence.

Previous flood experience was one of the previously mentioned elements in the PMT framework as a psychological variable, and it was expected to a have positive influence on flood adaptation decision. As expected, it had positive and statistically significant influence. Previous flood experience positively determines current flood adaptation decision. This is because flood adaptation is a dynamic, not a static, problem in which the extent of damage from previous flood determines the level of motivation and preparedness for anticipated flooding hazard by farm households. A result from [57], the study also concludes that a first flood event can serve as a wake-up call by creating awareness, preparedness, and improvements in institutional responses.

Adaptation to flooding is uncertain, as the consequences of climate change are complex, since it involves the interactions of social, economic, demographic, spatial, and natural systems that vary across space and time. There are a lot of issues that explain the dynamism of flood adaptation. For instance, the higher the return (income) from the investment on flood adaptation measures, the better the economic status of households to take additional and relatively complex measures. The more effective the adaptation measures taken on a single farm, the greater extent the household would be encouraged to adopt adaptation methods on other farm plots, too.

This further implies that adaptation is an investment form whose level of return determines individuals' willingness to take action to offset the negative effects of flooding. The positive and significant sign of previous flood experience also implies that as the frequency of flooding experiences increases, farmers decide to adapt and live together with the incidence. As flood happens repeatedly, this pushes farmers to be alert for the next harvesting time. The more aware households are of the occurrence of previous flood hazards, the earlier and quicker they take adaptation and mitigation measures against flooding.

Access to credit was one of the institutional variables included in the PMT model framework, and it was expected to promote flood adaptation decision behavior. As expected, except the construction of a dike as a long-term adaptation strategy, it had significant positive influence on flood adaptation decision regarding both short-term and long-term strategies.

Access to extension services is believed to promote better information dissemination for farm households. However, it was found to have negative insignificant influence on households' decisions on flood adaptation. This study, however, strived to note that the negative coefficient of access to extension does not necessarily imply the irrelevancy of the service. It may rather imply that the extension service is not properly practiced either by the practitioners or the households [47]. However, the average number of extension visits per year promotes flood adaptation decision by farm households, especially the application of long-term adaptation strategies.

6. Conclusions

The study relied on primary data on socioeconomic, psychological, and institutional variables to examine the determinants of flood adaptation decisions through the socioeconomic and protection motivation theory (PMT) model framework. The paper also aimed to explore the major flood adaptation strategies and constraints to adaptation in Fogera woreda. The study identified moving to high elevation places, selling cattle, seasonal migration, flood tolerant rice, planting trees, and construction of a dike as the most important prophylactic measures in the study area. On the other hand, farm households reported constraints such as lack of money, lack of labor, shortage of cultivated land, lack of membership to farmer associations, lack of attention, no support from government, and also lack of technological inputs to effectively respond to flood incidence.

The binary logistic regression results from both the socioeconomic and the PMT model on the determinants of flood adaptation decision showed that sex of the household head, marital status, family size, off-farm income, previous flood experience, access to credit, and average number of extension services have a positive and statistically significant influence on the household selection of flood adaptation.

Contrary to this, the age of a household head, education status, farm size, and access to extension have a negative but statistically insignificant influence on flood adaptation choice. The multinomial logistic regression model also showed that older farmers are less likely to take any flood adaptation measure except planting trees. The sex of a household head had heterogeneous influences on the selection of short-term coping methods and long-term adaptation mechanisms. Literate household heads were found to have lower level of willingness to take any adaptation measure. The results also showed that family size had positive influence on household decision behavior to flood adaptation strategies, both in the socioeconomic and PMT models.

Off-farm income was found to have a consistent statistically significant positive influence on the adoption of both short-term and long-term adaptation approaches. Farm size available for households had heterogeneous results. Previous flood experience was also another important psychological variable with a consistent positive influence on the adoption of both approaches of adaptations. On the other hand, access to credit had positive influence on the adoption of short-term coping methods and long-term adaptation mechanisms, except the construction of a dike. Access to extension was found to have perplexing results. It negatively influenced flood adaptation decision in the first place, but had a positive influence on the adoption of selling cattle, seasonal migration, flood tolerant rice, and construction of a dike, whereas it negatively influenced moving to high elevation places and planting trees. Similarly, the average number of extension visits also had heterogeneous influence on the choice of flood adaptation methods. From this, it can be concluded that households do not have the same demand to adopt any adaptation measure because of the peculiar nature of each measure.

Therefore, the study recommends that concerned stakeholders in the flood risk management system shall give ample and coordinated attention on the quality and effectiveness of training and education and access to extension services provided for households. The heterogeneous results of socioeconomic and institutional variables also imply that flood adaptation investment shall take into account the features, natures, and costs of each available prophylactic measure.

When analyzing the results of the study, it can clearly be established that the previous risk management strategies no longer work for households. The phenomena caused by extreme effects related to climate change cannot be treated with previous knowledge and experience. The need for external support, whether in the form of state intervention, community cooperation, or professional extension service, must be part of the lives of households. Rapid changes in environmental conditions, including water management (be it floods or droughts), manifest themselves in such an unpredictable way that households cannot follow adaptation patterns without professional data management and extension services.

However, problems related to the sustainability of international or global supply systems show that local supply systems (farm to fork), including households, can be the basis of a safe food supply in the next decade. According to the above, in the coming years, households can assume a much more decisive role in the process of local food supply, in which case the actions related to climate change and the adaptation strategies must be defined very precisely. Dealing with this phenomenon must be part of social and business innovation because it can already cause profoundly serious food supply problems in some parts of Africa or Asia. These phenomena, which can also result in various migration effects, are already associated with the most serious damage to the social system in the short term.

For future research directions and gaps, we suggest the following. Agricultural publications related to climate change primarily reveal the problem ethics of the phenomenon of drought and water scarcity, which represent extreme challenges in almost any part of the world. The frequent floods appearing in certain agricultural areas received much less emphasis in the development of adaptation strategies, which is why the specialized literature is also more modest. So that weather anomalies and water treatment issues are properly emphasized and provide professional answers, many analyses are needed in these areas in the future as well. Although the sample area we analyzed and the households located there are not representative of other flood-prone areas, they clearly show that traditional agricultural tools are not sufficient to overcome the challenges associated with rapid changes and adaptation.

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MDPI

Systematic Review

Smallholder Farming during COVID-19: A Systematic Review Concerning Impacts, Adaptations, Barriers, Policy, and Planning for Future Pandemics

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Abstract: Our broad aim was to systematically analyse research on the effect of COVID-19 on smallholder farming during 2019–2021 and to discuss how the research could be beneficial to smallholder farm resilience to future pandemics. The review methods were based on PRISMA guidelines, and 53 articles were included in the final review. The review aims to document the social-economic impacts on different groups, barriers and opportunities of smallholder farmers adapting to COVID, and policy options. Barriers to adaptations were considered in only 15% of journal articles, suggesting a research gap. This review highlights the fact that, among others, technology access to ensure information and crisis communication that specifically targets smallholders, as well as multi-layered diversification, serves as good predictors of smallholder adaptation to COVID-19. Multi-layered diversification includes product diversification, market diversification and income stream diversification. This confirms the established knowledge in disasters and livelihood studies where diversification of livelihoods portfolio serves as the key factor to resilience against shocks and crisis. Finally, we summarised the different policy implications arising from the literature. This implies that governments must develop an effective policy-mix that leaves no smallholder farmers behind in future pandemics.

Keywords: logistics; supply chains; extension services

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1. Introduction

COVID-19, a zoonotic disease, has caused unapparelled global disruption, sickness, and death. The threatening nature of the virus has been an urgent concern for governments. Governments sought to limit the spread of COVID-19 and its variants [1,2] and prevent illness and death [3,4] by implementing severe lockdowns and social distancing laws [5–9]. Governments and communities faced unprecedented global and national economic impacts [10]. Food security was a significant concern during the pandemic for governments. Agricultural services were required to respond to many countries' food shortages caused by COVID-19 [11]. However, governments were not always able to respond to farmers' needs because of the crippling effect of COVID-19 on the economy [12]. Furthermore, in many countries, small-scale farming is a vital food source for growers and those who purchase food at their local markets [13].

The travel restrictions introduced to minimise the spread of COVID-19 increased the impacts on and disruptions to farmers [10]. Many small-scale farmers were severely impacted as they could not obtain the necessary inputs and overcome transport interruptions. In many countries, small-scale farmers urgently required support to ensure food supply [7] due to the impact of COVID-19 on supply chains and logistics [10,12]. An analysis by Asegie et al. [13] in Ethiopia found that 88.89% of smallholder farmers' households were impacted by COVID-19. Interruptions have led to heavy losses and the destruction of the entire produce of some farmers [13].

Additionally, during COVID-19, logistical impacts on international trade impacted the supply of food accessed internationally [14,15]. The reduced availability of imports substantially increased the demand for locally produced food [16]. In response, farmers and those employed in associated sectors adopted various adaptations to mitigate the impacts of COVID-19 [17].

Recent systematic reviews related to the impacts of COVID-19 have included reviews focused on the impacts of COVID-19 on diet quality, food security, and nutrition in low- and middle-income countries [18]; the impact on the food supply chain [3]; supply chain management and development inspired by COVID-19 [19]; agricultural technological adaptation to the COVID-19 [20,21]; the immediate impacts of the first wave of the global pandemic on agricultural systems worldwide [22]; the transformation of the food sector, resilience, and security [23]; animal welfare and livestock supply chain [24]; frameworks of vulnerability, resilience, and risks [25]; food supply technology [21]; agrifood entrepreneurship [26]; food security in the first year of COVID-19 [27]; livestock systems and food security in low and middle-income countries [28]; impacts on African nations [29]; and global food security [30]. The systematic literature reviews cover many significant topics. However, none specifically focus on the smallholder farming sector. Publications by Asegie et al., 2021 [13] and Magar et al., 2020 [4] conclude that there needs more evidence of the systematic impacts of COVID-19 on the small-scale farming sector. Prior to any discussion on how smallholder farmers can improve their resilience to pandemics, there is a need for systematic evidence on the impacts, adaptations, barriers to adaptations, and recommendations concerning COVID-19 which policymakers, researchers, and NGOs may use to mitigate the impacts of future pandemics. This study will assist researchers in identifying gaps in the existing research on small-scale agriculture and "identify questions for which the existing evidence provides clear answers and thus for which further research is not necessary" [31]. We systematically document the available knowledge on COVID-19 impacts, adaptations, barriers to adaptations, policy suggestions, and research gaps. This study aims to:

(a) Identify, document, and discuss COVID-19 impacts on the smallholder farming sector;
(b) Identify, document, and discuss adaptation responses;
(c) Identify, document, and discuss policy and research gaps regarding impacts and adaptations;
(d) Identify, document, and discuss barriers to adaptations;
(e) Commence a discussion on preparing for future pandemics based on the results section.

2. Research Methodology

We conducted a systematic literature review (SLR) using peer-reviewed literature published in four databases (Scopus, Web of Science, Agricola, PubMed) during 2020-2021. We followed the PRISMA guidelines for systematic review and used NVivo to analyse and code the studies.

2.1. Search Strategy

We tested initial search strings before determining the final string: "covid-19 OR corona OR covid19* AND smallholder* OR small-scale OR subsistence OR peasant." Literature that was either published or in the press was included. The search was limited to English publications.

2.2. Selection Phase

Publications were exported to 'EndNote' and were analysed to ensure the publications met all the criteria—this occurred after entering the query string into a relevant database. We defined the following exclusion criteria:

- Studies that lacked a clear focus on COVID-19.
- Studies that did not refer to smallholder farming (except in small-scale and large-scale cases).
- Studies about small-scale forestry and aquaculture (due to variations in production).

The initial search yielded 1790 studies—50 duplicated studies were removed, and 966 from irrelevant fields were excluded. The remaining 774 studies were screened. A rigorous screening process was applied—300 studies were read in full and were coded in NVIVO; 200 studies required us to read the abstract, introduction, discussion, and conclusions to decide if they should be included, and finally, 274 studies required us to read the title and abstract to decide if they should be included. Seven articles could not be retrieved. Fifty-three studies were used for the analysis. The screening technique was based on the 'Preferred Reporting Items for Systematic Reviews and Meta-Analyses' (PRISMA), 2020 (see Figure 1). (A table showing the 53 included articles can be found in Table S1 in the Supplementary Materials section).

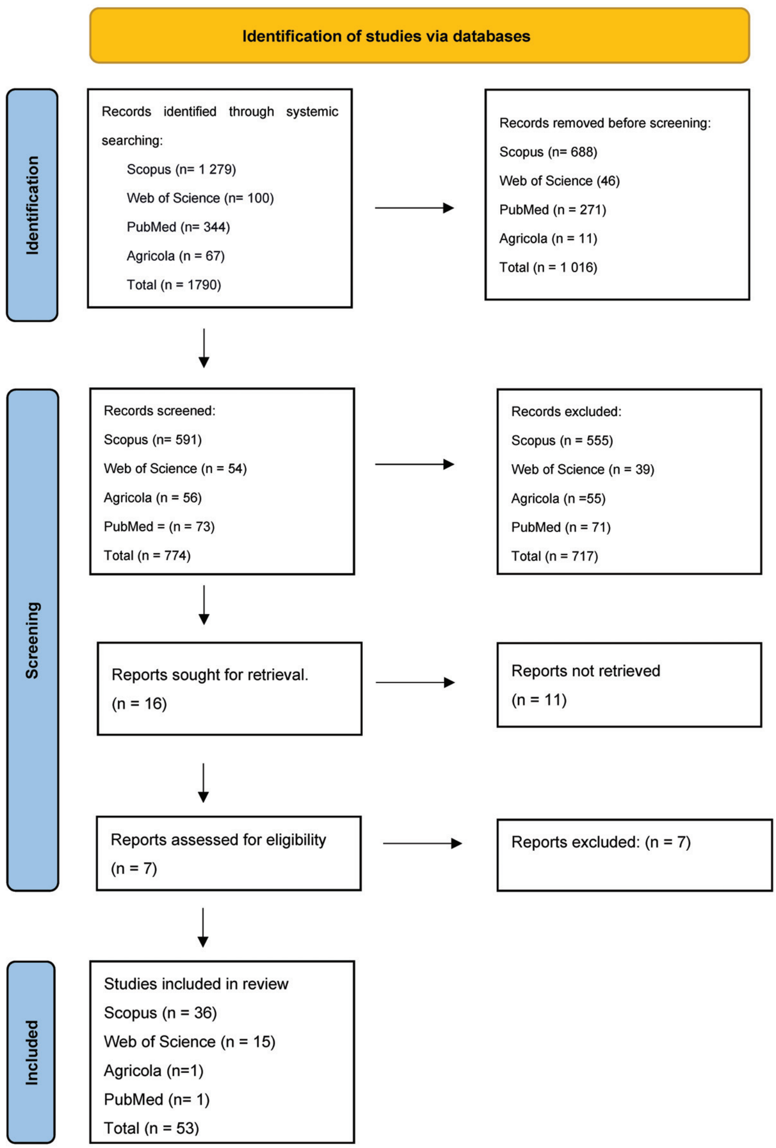

Figure 1. PRISMA 2020 flow diagram for SLR (included searches of databases only).

We included some studies that made a significant statement about smallholder farming during COVID-19, even if the main focus was not on smallholder farming.

2.3. Analysis

NVIVO was used to code the studies. NVIVO has been designed for researchers completing primary research or literature reviews. The program enables the coding of studies and notes, the completion of word searches, text mining, the construction of maps, and further exploration of nodes. See Figures 2 and 3. Extensive knowledge concerning impacts, adaptations, barriers to adaptations and policy, and research gaps were analysed and synthesised using NVIVO as our knowledge repository. Then, Excel was used to synthesise our analyses and the results further. The systematic review results section is based on NVIVO and Excel analyses. The discussion section is based on the results of the analyses documented in the results, insights, and suggestions based on our agricultural science experience.

Figure 2 provides a snapshot of the process. The themes and subthemes are shown as the features and drop menus available for coding and analysis.

Figure 3 shows the results of the text searches that we completed. The number of files that contained the search word or phrase was found in the files. The texts highlighted the word or phrase.

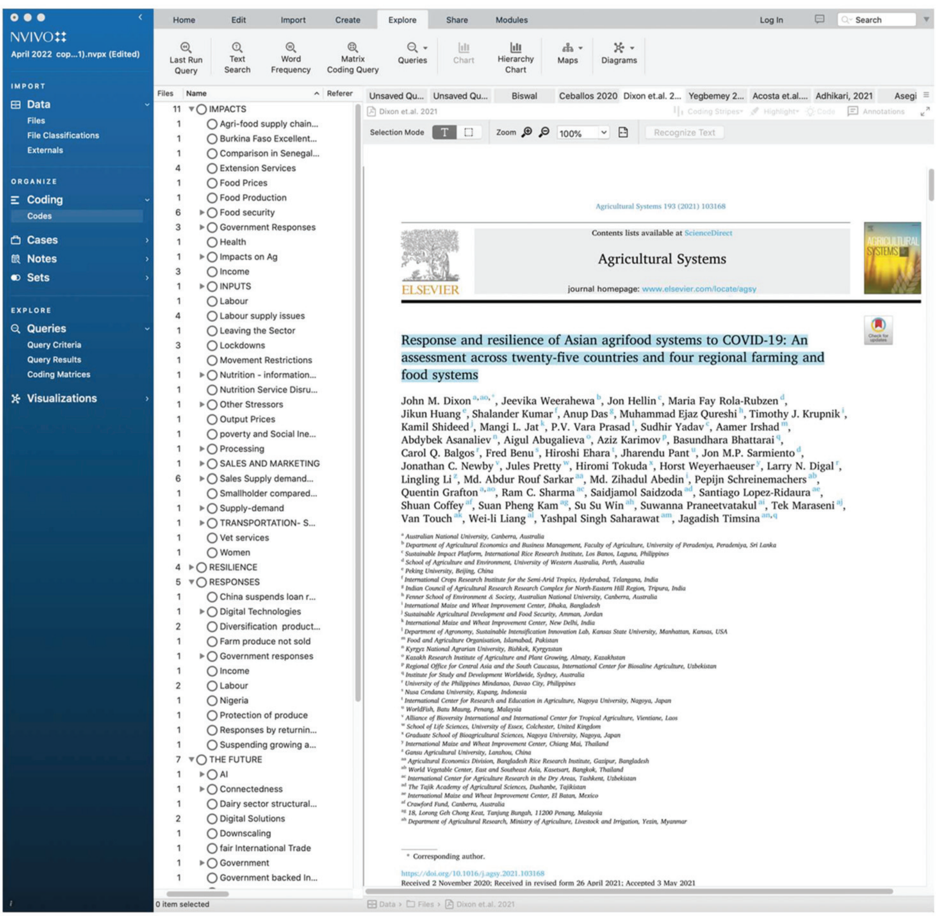

Figure 2. NVIVO code development.

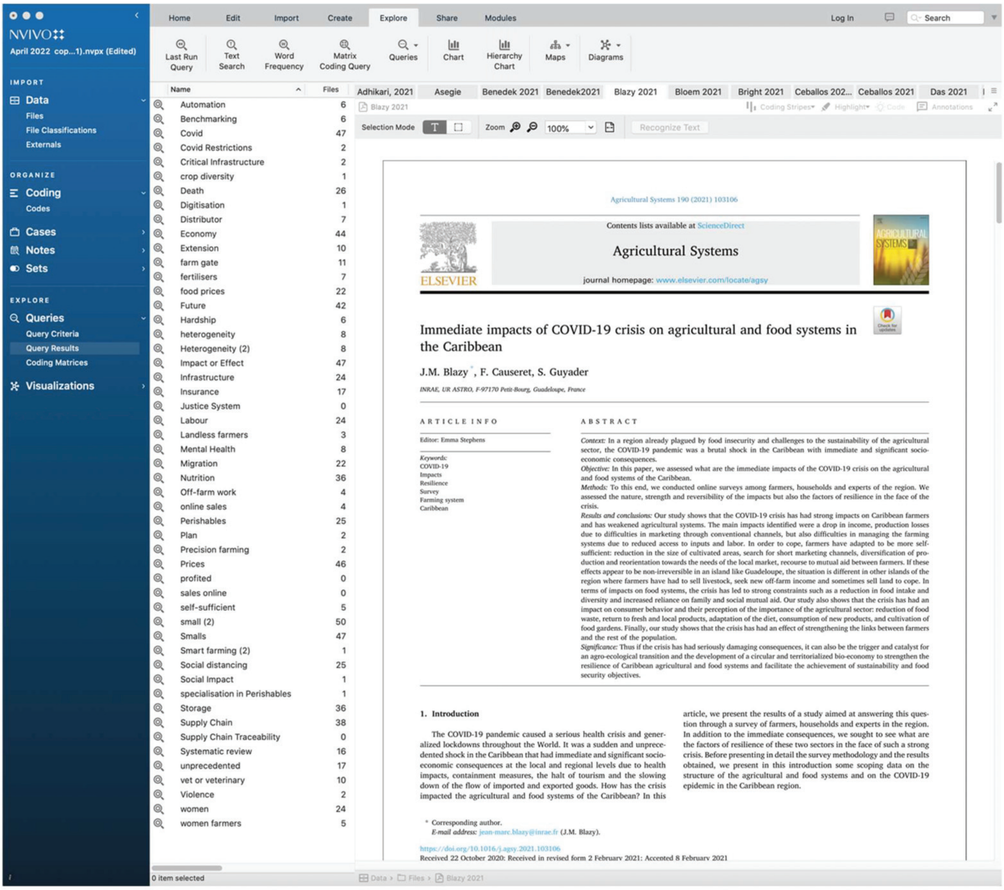

Figure 3. NVivo text searches.

3. Results

This Result (Section 3) documents the results using maps, tables, and texts. All the information in the results section was found while analysing publications in NVIVO and Excel. The discussion section (Section 4) discusses the results and insights of the authors of the systematic literature review. Sub-sections such as 4.5 (Options for Adaptations) discuss the results through the lens of what is required to ensure that smallholders will be resilient to future crises.

3.1. Description of Studies

In total, 25% of the publications were published in 2020 and 75% in 2021. The locations with the highest number of studies included India, Senegal, the Sub-Sahara, and Southeast Asian countries (see Figures 4 and 5).

We found a variety of data sources for secondary data, including reports, peer-reviewed studies, panels, the US Bureau of Statistics, blogs, media, and primary data sources, including farmers, NGO workers, government agencies, experts, academics, value chain agents, senior-level managers, agro-industrial companies, importers, and supply chain actors. In total, 68% of the data were from developing countries, 12% were from developed countries, and 20% were from a global perspective. In developing countries, there was more than twice the number of primary studies (227%) compared to secondary studies. See Table 1.

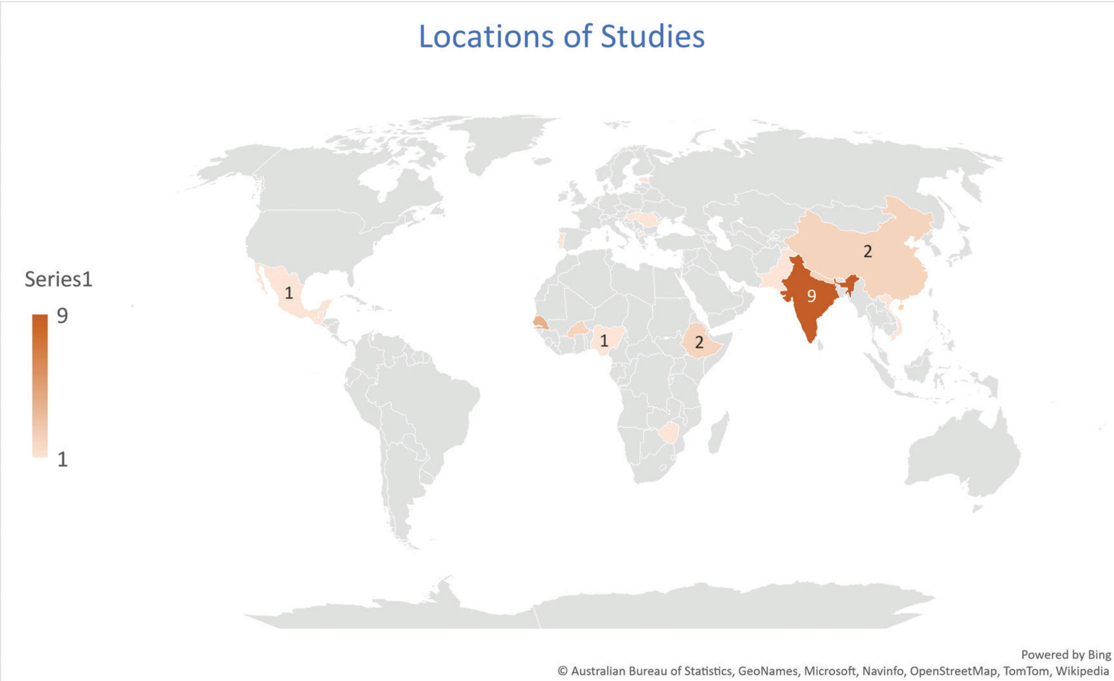

Figure 4. Map of locations of studies about smallholder farming (2020–2021). NB: Mouse-over enabled.

Table 1. Table displaying types of data at country and global level.

Data Source	Primary Data in a Developing Country	Primary Data in Developed Country	Primary Data Global	Secondary Data Developing Country	Secondary Data Developed Country	Secondary Data Global
No. of publications	25	3	7	11	3	4
Percentage of publications	47%	5.60%	7.50%	20.80%	5.60%	13.21%

There were seven primary studies with a global perspective (one comparative study and six subject reviews) and four secondary studies with a global perspective (review studies).

In a third of all the studies, the researchers used digital technologies to collect data, including phone and short text message surveys and online surveys. In contrast, in the other two-thirds of the studies, the researchers collected data using nondigital technology, including face-to-face surveys, interviews with farmers and key informants, panel discussions, and focus groups.

Most studies were about mixed farming (59%), while 26% were about crop farming and 15% were about livestock production. Thirty-one studies were about small-scale farming, and twenty-two were about a mix of small- and medium- or large-scale farming. The farm methods included organic farming (5 studies), traditional farming (1 study), climate-smart farming (3 studies), and conventional farming (1 study). However, 75% of the studies did not specify the farming method used.

In total, 57% were primary data, 34% were secondary data, and 9% were both.

Figure 5. Locations of studies naming specific regions and counties.

3.2. Socioeconomic Impacts of COVID-19

Two main classifications in the research on the socioeconomic impacts of COVID-19 on small-scale farming were found: economic impacts on farm production and social impacts on farmers (see Table 2).

Table 2. Main impacts of COVID-19 on small-scale farmers and members of farm households.

	Main Impacts on Small-Scale Farming	Percentage of Studies Mentioning Impact
Economic (or farming)	Supply	100%
	Markets	100%
	Incomes	96%
	Labour	94%
	Access to farm Inputs	81%
	Production planning	4%
	Decline in Tourism	25%
Social impacts on farmers or members of farm households.	Impacts on male farmers include increased workload.	19%
	Impacts on women include increased violence against women and reduced access to food.	51%
	Impacts on children include malnutrition and reduced access to education	42%
	Impacts on the aged include increased health vulnerability and reduced access to retail channels.	23%

The most mentioned impacts were disruption to supply (100% of studies) and disruptions to markets (100%), followed by labour shortages (94%) and interruptions to input supply (81%), and the least mentioned impact was production planning (4%).

3.2.1. Supply

All studies discussed impacts on supply, including supply chain interruption, interruptions to the supply of food to markets, processors and consumers, and the supply of farming inputs.

Agricultural supply chains were interrupted most severely during strict and prolonged lockdowns. In India, lockdowns caused enormous distress for poor and marginal farmers [8,12]. In China, where the government adopted a radical and aggressive approach to lockdowns in village areas, the impact on farmers was significantly severe in the short-term. The long-term impacts are unknown [32]. There were reports that all the food depots responsible for distributing food to people in Mugu district in Karnali, Nepal, had become empty of food stocks, and people could not buy food at all [6]: "There was a serious shortage of chemical fertilisers for rice because of transportation restrictions" in Nepal [6], and "The most significant effects on crop production were from a reduced labour supply, which significantly reduced access to agricultural inputs, lack of transport and sufficient markets for produce, due to the movement restrictions" [12].

3.2.2. Labour

In total, 50 of the 53 studies contained references to labour. The results indicate that the theme of labour was a significant factor. Several subthemes were found, including labour shortages [5,8,10]; accessing family labour [6,13]; severe impacts on labour-intensive farm production [10]; mobility restrictions [5]; morbidity [5]; labour migration, including reverse migration [6]; diversification to accommodate labour shortages [16]; the severe impact on landless labourers [11,33]; and labour-saving technologies [6].

3.2.3. Inputs

Twenty-three studies contained references concerning production inputs. These results indicate that the supply of "inputs" significantly impacted some small-scale farms. Significant references to several subthemes were found. The themes included the subsidisation of inputs [34]; the access and delivery of inputs [6,35]; new technologies to enable the payment of inputs [10]; seed shortages [10,36,37]; a shortage of fertilisers [14]; reluctance to invest in inputs [11]; inputs for crop protection [38]; input price increases [39]; locally produced input networks [7]; the quality of inputs [6]; and fodder inputs [8]. The results indicate severe interruption to accessing inputs for many small-scale farmers. Finally the direct of supply of inputs may be required [40].

3.2.4. Incomes

Many smallholder farmer incomes were severely impacted by COVID-19. Ninety-six percent of the publications reviewed discussed the impact on income. The economic impact that COVID-19 had on income further impacted the social impacts by reducing income to purchase food and other necessities.

3.2.5. Markets

All studies in the SLR referred to markets, indicating severe impact on markets during COVID-19. During the COVID-19, lockdowns significantly impeded access to markets. Many markets closed [16,40,41], and others experienced shortages of available products [10]. Markets and farmers experienced price changes due to the slowing down of supply [10].

The tourism market was severely interrupted due to international travel bans. The interruption impacted farmers selling to the tourist market [41]. In Central America and Mexico, grains, vegetables, fruits, roots, tubers, and meat producers were most affected due to tourism [41].

3.2.6. Production Planning and Timing of Farm Activities

According to Abid and Jie [10], lockdowns that coincided with harvesting led to the destruction of crops. Lockdowns that coincided with seeding meant farmers had to postpone seeding activities and face a loss of income. Further, according to Ceballos et al. [42], COVID-19 severely disrupted farm production plans, and farmers needed help executing essential farming activities to schedule. The affected farmers may not have been able to harvest, fertilise crops, plant seeds, or control pests, depending on the stage in which the lockdowns occurred. In India, the distribution of farm produce during lockdown periods became impossible due to travel restrictions [42]. In Odisha and Haryana, India, farmers adjusted the timing of harvests. However, traders were unable to purchase them at the farm gate. The absence of farmgate sales significantly impacted the sale of wheat. Farmers could only harvest and distribute wheat after the lockdown commenced [42].

3.2.7. The Decline in Tourism

Twenty-five percent of publications discuss how smallholder farmers were impacted by the decline in tourism due to COVID-19. The tourism sector closed dramatically in many popular destinations. Smallholder farmers supplying markets were severely impacted.

3.3. Social Aspects

The literature contained significant research on the impacts on women, children, and the elderly. References to males were found in 10 studies. However, when males were mentioned, it was usually used in comparison to females. Middendorf et al. [43] were the only researchers to examine the social impacts of COVID-19 on males.

3.3.1. Women

Violence against women increased during COVID-19 [6]. The division of household food has been unequal during COVID-19, with women receiving a lesser share of the available food [6]. Malnutrition increased for women due to COVID-19 lockdowns [10], and women's household duties increased due to school closures. Many women already responsible for household duties performed extra work, including farm work, selling produce at markets, and educating the children [6,11].

3.3.2. Children

COVID-19 exasperated food and nutritional problems experienced by children in farm households [14]. Deep concerns exist about the increasing malnutrition, wasting, and stunting of children in developing countries [41,44]. Child abuse increased during COVID-19. Kang et al. [2] called for an increase in child protection and education services for children.

3.3.3. The Aged

The elderly were called upon to perform farm work during the COVID-19 due to labour shortages [6]. The elderly found it difficult to access mainstream retail channels [38]. The elderly were more vulnerable to COVID-19, which may have made it necessary for other family members to perform some of the elderly persons' duties [45].

3.3.4. Men

Male farmers have consistently reported increased workloads since the start of COVID-19, with many working alone [43]. Middendorf's study [43] on vegetable production in Burkina Faso found that workloads for men increased by an average of 16.8% and that 31% were unable to hire the labour required for farming.

3.3.5. Minority Groups

There appears to be a gap in the research concerning social impacts on minority groups living on smallholder farms, including people with disabilities, minority religious groups, and those with alternative sexualities.

3.3.6. Incomes

The social impacts of reduced or insufficient income were not found in the SLR publications. However, relevant factors such as reduced incomes and increased working hours shown in the results would have had a negative effect on relationships and mental health.

3.4. Adaptations

Forty (75.47%) studies referred to adaptations, indicating that adaptations have been a significant focus of the research. The main adaptation strategies are to access family labour, negotiate labour with locals, use digital phone technology, use other digital communication strategies, diversify products, and diversify markets (see Table 3).

Table 3. Adaptations mentioned and the percentages of articles in which they are found.

Adaptation Strategy	Studies Mentioning Strategy (%)
Technological	83% N = 44
Communication strategies	62% N = 33
Increasing Storage facilities	72% N = 38
Diversifying produce, markets, or income sources	34% N = 18
Increasing access to family labour	18% N = 9
Use of mobile phones or cellular phones	8% N = 4
Negotiating labour in the local community	4% N = 2

3.4.1. Technology

There has been a significant interest in technological innovations to assist farmers in coping with supply issues [46]. The technologies under research include artificial intelligence, big data, blockchain, cloud computing, the internet of things, and machine learning. Developing and emerging technologies possess enormous potential to improve production yields and soils, synthesise farm data, efficiently use fertilisers, and mitigate the impacts of disasters [46].

3.4.2. Communication

The theme of communication is discussed in 33 of the 53 studies, indicating that this is a significant adaptation. Many farmers utilise digital communication technologies to maintain the feasibility of their small-scale farms [41]. Communication technologies enabled farmers to make online purchases and sales when face-to-face communication was a high risk [47]. Digital platforms enable communication to strengthen buyer–supplier collaboration and lower food security and food shortage risks [10].

3.4.3. Digital phones

The use of digital phones and digitised phone platforms has increased significantly since the beginning of COVID-19 [44,48]. Mobile phones have enabled access to agricultural technologies and information regarding farming methods [44,48] Technologies accessible on phones can assist farmers with water optimisation, the appropriation of seeds, and determining optimum fertiliser levels and pesticide use [48]. As mobile phone infrastructure expands and phone ownership increases, mobile phone technology will significantly increase yields and reduce costs. The use of digital phones will dramatically enhance communication; however, in some remote areas, digital phone infrastructure is still required.

3.4.4. Diversification of Produce

Farmers who diversified production were more effective in adapting to the COVID-19 crisis. Farmers started small-scale diversification with vegetables [36]. To cope, farmers diversified production to meet the local market's needs [49].

3.4.5. Diversifying Markets

Farmers sought short marketing channels [49]. Some farmers diversified distribution channels and removed supply chain intermediaries [47].

3.4.6. Diversifying Income Streams

The diversification of income streams allowed farmers to act more flexibly [41]. Farmers could either increase or decrease farm activity. However, reliance on income streams other than farming may have had a negative effect if these streams were interrupted [10].

3.4.7. Storage

Due to the impacts on logistics, storage facilities were desperately required, especially for perishables that required cold storage facilities [1,50].

3.4.8. Accessing Family and Local Community Labour

In response to labour shortages, many farmers' adapted by accessing family labour and exchange labour with the local community [36].

3.5. Barriers to Adaptations

There were eight barriers to implementation documented in the review. These included the lack of government support to develop new technologies [10], a lack of information [8], the price of phone data [49], infrastructure [12], access to the internet [48], research that compares perceived impacts and actual impacts [48], AI (artificial intelligence) is in its early stages [46], and the inelasticity of demand for produce, meant farmers were unable to increase sales by reducing prices [51].

3.6. Policy

The publications either discussed the impact of policy or were concerned with developing policies to mitigate the impacts of COVID-19. Initially, governments developed policies to limit the spread of COVID-19 [1,2]. Policy restrictions severely impacted many farmers, and food shortages were imminent. Governments relaxed policy restrictions for critical economic sectors to ensure the supply of food and other essential services.

COVID-19 was an unprecedented event, and many smallholder farmers could not cope. Many researchers in this review developed policy recommendations to address the impacts on farmers. Eighty-seven percent of the studies included policy recommendations. Table 4 shows the target audience for different categories of recommendations. The percentages are calculated by assessing which audience is most likely responsible for developing or implementing the policy. Table 4, therefore, contains general estimates.

Table 4. Target audiences of recommendations.

Target Audience	Recommendations (% est.)
Government	31%
Policy Makers	21%
Research Community	6%
NGO	2%
Farmers	11%
Agribusiness	2%
Technologists	2%
Insufficient evidence	23%

We aim to document the results concerning policymaking in the results concisely. The discussion section discusses the results of developing a policy for future pandemic crises.

3.6.1. Demands in Governmental Policy Change

Policy recommendations directly addressed to governments by the authors are documented. Nchanji and Lutomia [39], in a broad statement, recommend that governments develop a range of policy interventions to revitalise and improve farmers' resilience [39]. Other authors provide the finer details about the actual policy. Family support, through various strategies, is a priority of many researchers. Hirvonen [51] espouses that governments need to ensure the availability of nutritious foods. Asegie et al. [13] recommend that governments focus on immediate and long-term intervention strategies to assist the most impacted families using social security and revolve funding mechanisms. Kang et al. [2] recommend that governments provide social security and a social security net. Nchanji et al. [39] call for livelihood relief. Abid and Jie [10] propose that governments invest in new technologies, sustain the flow of agricultural products along the supply chain, encourage banks to create easy and quick transaction methods, control food security and price, and launch commercial transaction apps. Adhikari [6] calls for governments to increase the mechanisation of farms and develop digitisation. Moreover, they call for an increase in food reserves and state that governments should provide smallholder farmers with cash support to develop fallow land. Biswal et al. [8] recommend that governments research all forms of farming to acquire the holistic information required to attract support for all sectors and revive value chains. Dilnashin et al. [12] call for governments to purchase a surplus product and to avoid export bans and import restrictions. They also call for mobility restrictions imposed by governments to reduce the spread of COVID-19 to be lifted to allow farmers access to markets. DU et al. [32] recommend that governments provide vocational education and training for family farm owners; develop a policy and market environment supporting the long-term, stable operation of family farms; and improve the agricultural insurance market by making it accessible to more agents. Haggag [48] recommends that governments intervene in predatory price increases. Ijaz et al. [50] recommend increased communication to ensure the continuous flow of inputs and outputs. Nchanji et al. [40] call for governments to support actors across the food supply system with input subsidies, livelihood relief, supporting innovation, further digitisation, and supporting bulk purchasing. Magar et al. [4] recommend that government assists farmers with technical services by institutionalising research and extension services and improving government coordination within the tiers of government.

3.6.2. Policy Directed at Policymakers

There are two direct policy recommendations for policymakers discussed in the review. However, many policy recommendations will become the policymakers' responsibility in practice. Meuwissen et al. [52] call for policymakers to decide whether regional and short-value chains are more resilient than transnational ones. They also call for policies to strengthen anticipatory capacities, consider whether connectedness in value chains and diversity can be integral to policy design, develop stress tests, and provide the resources necessary to enable the transition to maintain public goods and services. Yegbemey et al. [53] call for policymakers to design strategies to encourage farmers to adopt innovative market-oriented strategies with the assistance of government extension services.

3.6.3. Policy Directed at NGOs

There is one publication that recommends NGO policy development. Asegie et al. [13] recommend that government donor organisations provide immediate and long-term intervention strategies through the implementation of social security programs and revolve funding.

3.6.4. Policy Directed at farmers

Huss recommends that farmers build or invest in onsite storage facilities [1]. Ijaz [50] recommends that livestock farmers should first communicate with suppliers of consumables, feed distributors, and professionals such as veterinarians and meat processors to find solutions to secure inputs supply, farm services, and the meat supply chain. Secondly, farmers should talk with farmers associations to reach out to the policymakers to obtain compulsory exemptions for the transportation of feed, animals, and personnel. Thirdly, farmers should adopt strict precautionary and management measures at farms to avoid disease spread [2]. Benedek et al. [16] propose that farmers increase produce diversity.

3.6.5. Policy Directed at the Research Community

Thulasiraman [54] calls for focused research towards local food chain sectors, the development and revival of traditional food sectors, and technological interventions of traditional knowledge. Informal food sectors such as raw milk trading, jaggery production, and the cultivation and preservation of indigenous fruits, vegetables, and crop varieties offer excellent employment opportunities and considerable food availability when operated on a small scale. Nchanji and Lutomia [39] call for Agricultural Research Systems to support SMEs in developing innovative business models that enable them to cope with the effects of any ensuing pandemic.

3.6.6. Policy Directed at Agribusiness

Goswami suggests that agricultural cooperatives, SHG, or existing federal programs extend credit to smallholder farmers. Magar et al. [4] suggest that agribusiness adapts and supports farmers during a pandemic.

3.6.7. Policy Directed at Technologists

Thulasiraman [54] calls for focused research towards technological interventions to be used in pandemic crises. (A table summariising policies and adaptations can be found in Table S2 in the Supplementary Materials section).

4. Discussion

4.1. Insights from Previous Pandemics

Before discussing the significance of the results for future pandemics and what activities we would support concerning future pandemic crises, we discuss the impacts of pandemics pre-COVID and discuss and compare current smallholder farmers' adaptations with past adaptations.

Previous pandemics, including MERS-COV, SARS 2002-2004, the Avian Bird Flu, and the Ebola Virus, did not have the global impact of COVID-19. However, the impacts on smallholder farming were significant [55]. According to Gatiso et al., the impact of Ebola on agriculture and livelihoods was unequivocal evidence that epidemics adversely impact livelihoods [55]. Gatiso et al. found that the impacts may have long-lasting effects on livelihoods, even for those not directly impacted [55]. Feuerbacher et al. reported that infectious disease depletes farmers' access to their primary asset, labour, due to premature deaths and morbidity [56]. Muteia et al. found that 21% of Nigerian smallholder poultry farmers lost between 80-100% of their income [57]. Considering the evidence, we assume that future pandemics will affect smallholder farmers.

The literature on adaptations for smallholder farmers before COVID-19 was comprehensive; however, previous adaptations are less relevant to the impacts of COVID-19. Our analysis of the impacts showed that the main differences during COVID-19 include personal and workers' health and safety, lockdowns, supply, tourism, and international trade.

There has been recent significant interest in the literature concerning smallholder farm adaptations for climate change. However, research concerning adaptations required for pandemics should have also been a priority due to previous evidence concerning the adverse effects of past pandemics on smallholder farmers [56].

Previously, smallholder farmers in developing counties have used traditional adaptations such as accessing assistance from their local community [55]. They could not access modern adaptations due to personal financial constraints and the lack of access to credit [55]. However, the analysis of the current adaptations showed that some farmers in developing countries are applying modern technologies. For example, our analysis of online communication strategies showed that many smallholder farmers are using digital telephones. As a result, many smallholder farmers in developing countries can obtain farm management information using their mobile phones. Additionally, many farmers now belong to online communities and can discuss farm management issues with other farmers.

COVID-19 has led to a significant increase in research about the impacts on smallholder farmers and their adaptations during pandemics. However, we found that measurements of both the impacts and adaptations were previously, and continue to be, severely limited. Birthal et al. [58] recognised the importance of empirical evidence and descriptive and inferential statistical methods applicable to impacts and adaptations. They applied these to their study on smallholder farming.

Finally, we assume that preparation for all future pandemics is impossible due to the uniqueness of pandemics. However, we believe that the information from this systematic review is invaluable to future policies to mitigate the impacts of pandemics on smallholder farmers. Further, pre-COVID research on adaptations is also invaluable.

4.2. Description of Studies

4.2.1. Years of Publication

The small number of publications in 2020 could be due to travel restrictions and researchers' concerns about completing the research. Our view is that future unprecedented pandemics may result in a similar experience. Furthermore, future pandemics that are more dangerous than COVID-19 could seriously prohibit research activity, particularly during the early stages.

4.2.2. Locations of Studies

Research during COVID-19 was mainly conducted in the Sub-Sahara region of Africa, SE Asia, and China. We espouse that researchers should have specified why the research was undertaken in a specific region. We can speculate that researchers are interested in researching developing regions as they are home to a large cohort of small-scale farmers. There was broad concern from humanitarian organisations that smallholder family households may return to poverty in these regions. There may be other reasons why little research was completed in other regions. This may be because the smallholder agricultural sector was marginal in some regions or the spread of COVID-19 was less severe or even non-existent.

Furthermore, many countries have social welfare nets that protect smallholder farmers, thus making the need for research less urgent. The main problem concerning mitigating future pandemics is that impacts may be more severe than those of COVID-19, which could threaten food security. The adaptations required will depend on the nature of the pandemic. Regions previously unaffected may still be impacted in the future. Furthermore, previously unaffected regions may need to take adequate precautions. We recommend that any country with a significant smallholder farming sector be prepared for all forms of future pandemics.

4.2.3. Data

The data analysis showed that primary data far outweighed secondary data. Considering the dangers of conducting research, this result was unexpected. A significant result was that two-thirds of the data were obtained from face-to-face surveys, interviews with farmers and key informants, panel discussions, and focus groups. Concerning future pandemics that prove more lethal and contagious than COVID-19, it may not be possible to gain any of these types of data, which would severely affect attempts to access vital data. Researchers must use safe methods to provide good data before conducting research. Farmers in areas where it is impossible to access digital data or farmers who cannot afford digital data may be severely affected. The result may leave smallholder farmers in the dark when attempting to access vital knowledge related to their family household and farming needs. Communicating research findings and participating in research that benefits smallholder farmers are additional reasons why all smallholder farmers should have access to mobile phones.

4.3. Economic Impacts

Economic impacts, including those on supply, markets, incomes, labour availability, and access to farm inputs, as well as interruptions to production planning and the decline in tourism, are all impacts that may have been severe for most or many smallholder farmers. The economic impacts found in the results need to be included in policies for future pandemics. The adaptations suggested for each are discussed in the following section.

4.3.1. Supply

Supply systems were severely interrupted initially [8,12] and during prolonged lockdowns, and this forced farmers to adapt and change production plans [10], which included the diversification of produce [36,49], diversifying markets, or suspending production [42]. Supply systems include farming input supplies and supplies to markets and processors. Some smallholder farmers lost their entire livelihood due to supply. Supply may be the most crucial factor in future pandemics, but fortunately, new technologies are under development, and logistic practices are continuously improving. Future supply logistics are likely to be far more sophisticated than the supply system of the COVID-19 era.

4.3.2. Markets

The results showed that lockdowns significantly impeded market access [10,16,40,41,59] including closing or having supply shortages. Markets also experienced price changes. A policy that ensures fair prices during a pandemic may help in future pandemics. Additionally, the government should address predatory pricing policies [48].

4.3.3. Incomes

Despite several media publications stating the agricultural sector was the least impacted economic sector, only decreasing production by three percent, these data were not specific to smallholder farming. The impact on the smallholder sector was likely to be far greater than three percent. To prepare for future pandemics, accurate results are required. More accurate information could be found if governments conducted a special census on COVID-19. While it is unlikely that they will conduct a special census, taxation records might assist in assessing the income impacts of COVID-19 on smallholder farmers.

4.3.4. Labour

The results showed that farmers found difficulties obtaining labour [5,8,10]. Adaptations to access labour were limited to accessing family and community members wishing to take the risk, probably because they needed to feed their families. We recommend governments develop employment services and safe transport options for the transmigratory movement of immigrant workers. Farmers can prepare for future pandemics by building safe buildings for their workers.

4.3.5. Access to Farm Inputs

Access to farming inputs is a critical aspect of the supply system for smallholder farmers. Shortages of fertiliser [14] and seed [10,36,37] and fodder [8], and farmers' ability to store quality inputs must be addressed in policy for future pandemics. We recommend adaptations that use farm resources, such as producing fertilisers or producing seeds. Supplying seeds for personal use can be easily accomplished with crop seeds such as corn, rice, and wheat.

4.3.6. Production Planning

Two publications from the review discussed production planning [10,42]. This was likely due to more excellent farming knowledge or a more rigorous approach by the researchers. Production planning must be included in future pandemic policies so farmers can be better prepared and respond by making changes more flexibly.

4.3.7. Impacts on Tourism

Many smallholder farmers supply to local markets; however, a significant number supply to the tourist market [41]. Future pandemics, at least as contagious and lethal as COVID-19, will likely result in closures to tourist destinations. Smallholder farmers may need to rely on subsistence production and look for other sources of income. Others may survive or help others survive by sharing produce within their local community. We support and recommend developing community-based support groups to help others during a crisis.

4.4. Social Impacts

Policies to mitigate the social impacts are also required, as outlined in the discussion below.

4.4.1. Impacts on Women

The impacts showed an increased level of violence toward women [6], an increase in malnutrition [10], and an increase in workloads [6,11]. Another factor that may have impacted women is a decreased income, causing marital disputes and increased pressure on women (and others). We support the development of services for women experiencing violence or mental health issues and support these services being boosted during times of pandemics. We also support government efforts to increase awareness and the use of social media as new pandemics arise.

4.4.2. Impacts on Children

During COVID-19, there was an increase in child abuse [2] and malnutrition [14] among children. We strongly support the development of government services to monitor and act on child abuse and the development services to monitor children's diets and ensure they receive nutritious and adequate meals.

4.4.3. Impacts on the Aged

The aged were more vulnerable to COVID-19. Some were less able to assist with household work [45], but other aged persons were called upon to assist by helping with household work [6]. Some of the aged were less able to access food from markets and access services [38]. We support the development of increased aged services to support the elderly and the preparation of services and policies for the aged during pandemics.

4.4.4. Impacts on Males

Generally, males were better able to cope with COVID-19. Many men worked more hours during COVID-19 [43]. We support services for men unable to cope during pandemics, even though men may be reluctant to seek these services. Men's use of services should be monitored and resourced as needed.

4.4.5. Impacts on Minority Groups

The results showed a research gap concerning minority groups. Minority groups may have been excluded because they cannot communicate their needs. We support the development of research to identify minority groups and their experience during COVID-19. If it is found that minority groups cannot communicate their needs, we support the development of services that enable minority groups to do so.

4.4.6. The Social Impact of Reduced Income

The domestic tensions caused by a lack of income may increase domestic violence. We recommend that all governments provide safety nets for citizens who fail to provide adequately for their families and themselves. Furthermore, a person's capacity to work is often misjudged. People with disabilities may look able to work but cannot work full-time. We recommend government policies to assist all people with inadequate incomes to achieve a good quality of life, thus reducing household stress and domestic violence.

4.5. Options for Adaptations

There were eight significant adaptations documented within the results section of the review. Policymakers should identify the adaptations that can be easily implemented in the region they are developing and consider strategies to enable adaptations with significant barriers.

4.5.1. Technology

New technologies can transform smallholder agricultural systems. This may result in higher profits for farmers and smallholder farmers, enabling efficient supply systems during pandemics and the automation of production processes. Many farmers are already taking advantage of new technologies. Automatic computer-controlled farms already exist. This offers significant opportunities for smallholder farmers. Smallholder farmers could combine farms by sharing the costs and benefits of automated farming. Access to additional finances is improving, and financial institutions will be able to see the benefit for farmers and their companies. Some smallholder farmers may view this as a pipe dream. However, if a suitable model is produced locally or even nationally, they will see the benefits and may come on board. Automatic farms can significantly reduce the effects of pandemics on smallholder farmers. There would be less or no need for labour, and produce would be safe, clean, and disease-free with onsite testing. We recommend developing technology to create noncontact agricultural systems, including using automated vehicles to supply produce during pandemic events.

4.5.2. Communications

The results showed that developing communication technologies could assist many smallholder farmers [10,41,47]. Half a century ago, many of these communication technologies were non-existent. Older farmers who have watched and adapted to these new communications and younger farmers who have learnt these skills at school now have the skills to conduct most of their marketing and sales, observe daily changes in daily prices, order inputs, and obtain essential information relevant to their business needs. Younger farmers who have learnt these skills could find supplementary work by assisting older farmers lacking the newer communication skills. The communication strategies will assist farmers in confidently growing produce for local demand, locating processors, negotiating prices, organising safe and personal delivery, and creating online shops. Farmers with the necessary skills will be well positioned to negotiate better deals with intermediaries because of their power to negotiate online directly with processors, access a wide range of markets, and find new local customers. With new computers, such as Chromebooks, available at a fraction of the cost of regular computers, more smallholder farmers can afford to take advantage of new communications. Ideally, smallholder farmers need both a low-cost computer and a digital phone to take full advantage of the new opportunities available to them. We recommend that further education be provided for all farmers who still need to develop skills in communicating online.

4.5.3. Digital Phones

Digital phones were beneficial to smallholder farmers during COVID-19. Minicomputer digital phones can be carried in your pocket, making it possible to access information, receive calls, and conduct business at all hours. Smallholder farmers can use digital phones to access the information sites necessary to run their businesses and keep up with local news concerning lockdowns and transport restrictions [44,48]. The use of digital phones has been proven to be very useful during COVID-19, and farmers should make every effort to purchase a digital phone if the necessary infrastructure is available. Further, it recommended that all governments provide digital phone infrastructure. Digital phones are of even greater value during a pandemic crisis when face-to-face services are unavailable due to restrictions.

4.5.4. Diversification of Produce

The results relating to the diversification of products have proven to be effective [36]; however, the ability to make the right decisions regarding which crops to diversify is complex, and farmers will require assistance from agricultural extension services to ensure the soil and climate is suitable. Smallholder farmers will require assistance to learn how and when to grow crops they have yet to grow. However, with the right choices and education, diversification is relatively implementable by smallholder farmers. To prepare for future pandemics, we suggest extension services encourage and assist farmers in growing new crops and produce and keep continuous records to ensure the right choices are made during a pandemic. An obvious choice for farmers is growing non-perishable crops during periods when supply is severely interrupted.

4.5.5. Diversifying Markets

Diversifying markets creates more opportunities for smallholder farmers to sell their produce. If dealing with an intermediary who becomes unable to work due to illness or dies, the smallholder farmer has no choice but to explore new markets or lose most or all their produce. Smallholder farmers with market options will gain leverage in the market and will be able to negotiate fairer prices. Additionally, shorter distances to travel will reduce the risk of being exposed to a pandemic.

4.5.6. Diversifying Income Streams

Diversifying income streams enables smallholder farmers to supply family needs and finance their farms [41]. The ability to finance farm operations after a farming crisis would be invaluable to smallholder families. However, many smallholder farms lost additional income streams during COVID-19. There has been considerable interest in enabling smallholder farmers to access credit, and this looks set to improve.

4.5.7. Storage Facilities

Storage is critical for smallholder farmers. Cold storage is desperately required for growers of perishable produce such as fruits and vegetables [1,50]. The government has already commenced a storage program for smallholder farmers in Indonesia. All governments without adequate storage for the smallholder agricultural sector should follow Indonesia's lead.

4.5.8. Accessing Family and Community Labour

Accessing family and local labour is common for smallholder farmers in many countries [36], particularly during seeding and harvest. Both seeding and harvesting can be completed in 2 to 3 days on small farms. Smallholder farmers accessing local labour will not need to house their workers.

4.6. Barriers to Adaptations

Eight adaptations were found in the review, all of which need to be addressed by the government [8,10,12,46,48,49,51]. A government's ability to address these barriers may be limited or impossible due to financial and physical constraints. Many developing countries cannot and have never, in the past, been able to afford to assist with these adaptations, such as developing new technologies and providing roads, storage, and digital phone infrastructure. For example, in Indonesia, where approximately 50% of Indonesian farmers are smallholders, there are over 6000 inhabited islands, many of which are difficult or impossible to service.

Additionally, many developing and developed countries have suffered huge debts due to the impacts of COVID-19, limiting the support governments have been able to give to smallholder farmers and efforts to become more resilient to pandemics. The solution for farmers unable to benefit from the adaptations with significant barriers will be to either operate their farms as usual, if possible, or use those adaptations without barriers, such as the diversification of products, making sales locally, or looking for additional work.

4.7. Policy for the Future

The results have shown which policymaking group should be responsible for each policy aspect. The following discussion aims to provide practical policymaking advice based on our results and knowledge of agricultural science. The aim is to discuss policies for future pandemics.

4.7.1. Government Policymaking

The results section of this review showed that researchers have been able to specify significant policy recommendations for governments. The recommendations for the government will be of interest to government-employed policymakers. The results indicate that family support, including cash payments and providing nutritious food for families, is a significant priority of those researchers making policy recommendations for the government [2,39,52]. Farming support through cash and providing seed and fertiliser to keep the farms operating should also be a priority. Government research, technological development, and the provision of storage facilities should be priorities for governments because of the substantial impacts on supply that severely impact smallholder families.

4.7.2. Policy Development for Policymakers

Policymakers exist within governments, research institutions, and business organisations; policymakers should include farmers and others working in the smallholder agricultural sector. As stakeholders', farmers, transport workers, suppliers, and processors will have expert knowledge not available through other sources. Farmers have specialised experience in growing and knowledge regarding when to plant and what to plant. Policymakers who work with and engage with the smallholder agricultural sector will have access to insider knowledge that can improve policies for future pandemics. Agribusiness and farmers included in policymaking will be more likely to adopt policy suggestions directed at them.

4.7.3. NGO Policymaking

NGOs' strategy to support smallholders is understudied. Only one author discusses NGOs [13]. We support NGOs' engagement in family and farm management support. Additionally, research by NGOs will further enable NGOs to assist smallholder farmers in achieving resilience during pandemic crises.

4.7.4. Policy for Smallholder Farmers

Three policies documented in the results were directed at farmers concerning building storage, improving their communications, and diversifying produce [1,4,50]. Smallholder farmers will naturally consider new policies if they benefit their farming operations. The results showed that researchers have policies and adaptations specifically for smallholder farmers; however, the average farmer will likely never read a journal publication. Researchers must develop communication strategies to assist farmers in accessing the latest research. Our suggestions include contacting local media, newspapers and radio stations, supplying pamphlets to suppliers of agricultural inputs, and developing websites or blogs. Once farmers become aware of the advice, they can access it by listening to local radio, reading local papers, or obtaining a helpful pamphlet. The next time they purchase inputs or go to a website, they will likely seek the advice researchers can offer them.

4.7.5. Policy Directed at the Research Community

The research gaps discussed in this review may interest the general research community. The research gaps identified in this review and other gaps are further discussed in the discussion section.

4.7.6. Policy Directed at Agribusiness

Goswami et al. [36] suggest that agricultural cooperatives, SHG, or existing federal programs extend credit to smallholder farmers. Magar et al. [4] suggest that agribusiness adapts and supports farmers during a pandemic.

4.7.7. Policy Directed at Technologists

We support Thulasiraman's [54] call for policy interventions to be used by farmers during pandemics.

5. Research Gaps

Researchers have identified the following research gaps. Asegie et al. [13] identified research gaps on the impact of COVID-19 that captures the seasonality and resilience capacity of households and on COVID-19′s impact across the sex of household heads. Benedek et al. [47] identified a gap in the research concerning the clarification as to whether their findings on digital resources are generalisable.

Bloem and Farris [59] identified a gap in the research concerning COVID-19′s impact on different socioeconomic groups. Ceballos et al. [42] identified a gap in the research concerning smallholder farming household vulnerability, nutritional food quality, and family food distribution. Dixon et al. [11] identified a gap in the research concerning the impacts on natural resources, whether adaptations to the impacts of COVID-19 lead to a boost in farm sustainability and diversification and finally, whether COVID-19 will be a significant influence in achieving a green economy. Goswami et al. [36] claim that the accurate assessment of the impact of dual crises on agricultural systems and accounting for the adaptive strategies is still beyond our knowledge and opens the scope for future research. Iese et al. [60] identified a gap in the research concerning food sovereignty and the impacts and adaptations to COVID-19.

Going forward, there is an urgent need to invest in technological interventions to be used in pandemic crises [54]. Meuwissen et al. [52] identified a gap in European resilient farming systems research. Han et al. [61] identified a gap in the research concerning the risk of viral transmission in food. Lang et al. [62] and Nayal et al. [46] identified a gap in the research concerning the application of new technologies to improve supply chain management. Van Hoyweghen et al. [63] and Varshney et al. [64] identified a gap in the research concerning the long-term impacts of COVID-19.

The critical research gaps that we have identified while developing this review include the following:

(a) Research on the implications for smallholder farmers if a future pandemic is significantly more contagious and lethal than COVID-19.
(b) Research on the first responder's activity for smallholder farmers when an unprecedented pandemic occurs.

(c) The role of smallholder researchers and policymakers during the early stages of an unprecedented pandemic.
(d) Continued research on how to mitigate the impacts of future pandemics.
(e) The best ways to collect data during a pandemic crisis.
(f) Continuing research on supply logistics for smallholder farmers.
(g) Assessment methods to assess smallholders' readiness for future pandemics.
(h) Controlling predatory pricing of essential food during pandemic crises.
(i) Accessing labour for smallholder farms during a pandemic.
(j) Production of homemade fertilisers.
(k) Providing services for women, children, and the aged during a pandemic.
(l) Overcoming language barriers during a pandemic.
(m) The provision of essentials to smallholder farm households severely impacted by pandemic crises: Can we afford social security for vulnerable farm households? Cost–benefit analyses concerning the support of smallholder family households against the alternative?
(n) Continued research concerning strategies to overcome barriers to communication for smallholder farmers in remote areas.
(o) The provision of education to smallholder farmers.
(p) The role of government concerning smallholder farm resilience for future pandemic crises.
(q) The benefits of engaging farmers and agribusiness in policy development for future pandemic crises.
(r) The real impacts of adaptations impact on smallholder farming during COVID-19.

6. Limitations

It has been challenging to conduct primary research on farms due to COVID-19 restrictions. However, despite the restrictions on movement, 33% of primary research studies used digital methods such as online surveys, phone surveys, and SMS.

Variation in the number of studies from low to middle to high-income countries and comparative studies suggests variation in research ethics in the countries. Forty-one studies were from low and middle-income nations, suggesting a more flexible approach to research in those regions; Only three studies from high-income countries suggest stricter research in rich countries during COVID-19. More global (comparative) studies, including studies from high-income counties, will enable more reliable comparisons and, possibly, additional knowledge of the continuum of adaptation options.

7. Conclusions

This review systematically analysed and documented the impacts, adaptations, barriers to adaptations, policies, and research gaps concerning COVID-19 and future pandemics. The impacts on smallholder farming were sometimes severe. The literature regarding smallholder farming discusses many valuable adaptations; however, the actual quantitative results of their implementation have yet to be included. Therefore, further research on the impact of adaptations is required. Barriers to implementing adaptations were considered in approximately 15% of the journal articles. The review documented many policy issues that will be invaluable to policymakers.

Research gaps were discussed in approximately 20% of the review articles. Research gaps were included in the discussion to be a priority for future pandemics. Broadly, the review has documented a substantial and extensive repository of knowledge that can be used to mitigate the impacts of future pandemics. This has also enabled discussion concerning various issues, and many suggestions for further research have been formed.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/10.3390/land12020404/s1, Supplementary Table S1 and Table S2 include a table of the authors and works included in the systematic review and a table including policy and adaptation recommendations by authors. (In text citations are included).

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Article

Spatiotemporal Analysis and War Impact Assessment of Agricultural Land in Ukraine Using RS and GIS Technology

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Abstract: Military conflicts are one of the inevitable factors that can cause countries to suffer from food insecurity due to reduced agricultural productivity, increased food prices, and the deterioration of agricultural land and infrastructure. Farmland may become fallowed and abandoned as a result of reduced investment in agricultural management caused by military conflicts. To rapidly assess the impact of conflicts on agricultural land and food security, the utilization of effective and feasible methods for the regular monitoring agricultural management status is necessary. To achieve this goal, we developed a framework for analyzing the spatiotemporal distribution of agricultural land and assessing the impact of the Ukraine–Russia war on agricultural management in Ukraine using remote sensing (RS) and geographic information system (GIS) technology. The random forest (RF) classifier, gap filling and Savitzky–Golay filtering (GF-SG) method, fallow-land algorithm based on neighborhood and temporal anomalies (FANTA) algorithm, and kernel density method were jointly used to classify and reveal the spatiotemporal distribution of fallowed and abandoned croplands from 2018 to 2022 based on Landsat time series data on the Google Earth Engine (GEE) platform. The results demonstrated that fallowed and abandoned croplands could be successfully and effectively identified through these proven methods. Hotspots of fallowed croplands frequently occurred in eastern Ukraine, and long-term consecutive fallow agricultural management caused cropland abandonment. Moreover, hotspots of war-driven fallowed croplands were found in western Kherson and the center of Luhansk, where the war has been escalated for a long time. This reveals that the war has had a significant negative impact on agricultural management and development. These results highlight the potential of developing an accessible methodological framework for conducting regular assessments to monitor the impact of military conflicts on food security and agricultural management.

Keywords: remote sensing; geographic information system technology; agricultural land; military conflicts

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1. Introduction

Food security is closely linked to national economic development, social stability, and human survival [1,2]. The World Food Summit defines food security as a state where all people, at all times, have physical and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life [3,4]. However, several factors unsteadily affect national food security. For example, climate change (i.e., global warming and disastrous weather) and frequent human activities (i.e., urban construction and industrial development) enhance natural environment stress and cause the irregular and unhealthy growth of crops, which could lead to an increased risk of agricultural production and reduce the prospective return of agriculture [5–8]. Sociopolitical factors, including agricultural policy, financial assistance, and technological support, are directly related to the trend of national agricultural development and affect national food security [9,10]. Moreover, armed conflicts are one of the inevitable factors that can cause countries to suffer from food crises. The present, ongoing Ukraine–Russia war started on 24 February 2022.

Ukraine is one of the world's major agricultural exporters; it is rich in black soil resources and has a strong ability to produce grain and oil such as wheat, barley, sunflower, and maize. North Africa, the Middle East, and many European countries heavily depend on agricultural products exported from Ukraine [11–14]. However, as the war intensified, national food security and the environment faced a serious threat under the background of the global COVID-19 pandemic. The war zones in Ukraine cover many cultivatable areas. The land in the risk zones has been damaged due to military operations, and may no longer be suitable for cultivating crops until the ecological environment and agricultural production have been reconstructed and resumed [15,16]. Moreover, hindered transportation, rising food prices, and economic sanctions against Russia have aggravated the food crisis in Ukraine and other countries [17–19]. Therefore, due to the serious negative influence of agricultural productivity decline and food insecurity, it is necessary to understand the impact of the ongoing war on agricultural land use and obtain timely and accurate spatial distribution information of land use.

Crop cultivation reduction and cropland abandonment are potential outcomes of armed conflicts wherein production from cultivatable lands ceases due to the danger of attacks. However, cropland abandonment is difficult to map because of the lack of reliable information, which usually relies on field surveys implemented by special organizations such as the Food and Agriculture Organization of the United Nations (FAO) and Eurostat (Land Use and Coverage Area frame Survey, LUCAS) [19–23]. Compared with field surveys, which are time-consuming and have a limited ability to capture the spatial and temporal patterns of cropland changes, remote sensing is a promising technology that can rapidly, dynamically, effectively, and cost-efficiently monitor agricultural land use for large-scale applications and long-term trends [24–28]. Moreover, abandoned croplands are often defined as croplands that have not been cultivated for at least two–five years; in this situation, the comprehensive consideration of cropland management patterns over a long period is required [29]. Long time series of fallowed and active croplands could be an indication of land management intensity, which can be used to define abandoned croplands. Fallowed croplands can be defined as land without management for at least one to three years, which makes common classification models difficult to use due to its complex land status; for example, fallowed land may remain free of vegetation within a short time, and it may also regrow grass in a longer time [19,22,30]. The fallow-land algorithm based on neighborhood and temporal anomalies (FANTA) method was proposed to classify fallowed land without upfront training data in large-scale extents [31]. This method analyzes relative temporal and spatial greenness patterns to extract fallowed land information based on statistical indicators derived from long-term Normalized Difference Vegetation Index (NDVI) time series data. Without the need for field data for training, FANTA has the advantage of effectively monitoring the agricultural management status in regions where it is difficult to conduct fieldwork and obtain sufficient fundamental geographic data [32].

Temporally continuous NDVI time series data are essential for performing the FANTA method, which can reveal long-term vegetation dynamics within the cropland extent. Although the high temporal resolution data acquired via MODIS (Moderate Resolution Imaging Spectroradiometer) and AVHRR (Advanced Very High-Resolution Radiometer) are commonly used to calculate NDVI time series, coarse resolution data are unsuitable for fine classification [33–35]. Landsat datasets have great advantages for application, owing to their sufficient historical images with 30 m medium spatial resolution. However, high-quality Landsat NDVI time series data are difficult to obtain and are limited by cloud contamination and the satellite 16-day revisit cycle [36–39]. Therefore, two major methods for reconstructing continuous 30 m Landsat NDVI time series data are proposed: a temporal interpolation algorithm based on single Landsat data and spatiotemporal fusion technology by blending MODIS data with Landsat data [40–43]. The gap filling and Savitzky–Golay filtering (GF-SG) method is a newly developed NDVI time series reconstruction algorithm that generates synthesized high-quality Landsat NDVI time series data using MODIS NDVI time series to fill missing values within Landsat data. Subsequently, a weighted Savitzky–Golay filter was applied to remove the residual noise in the synthesized time series. The GF-SG method, proven to perform better, can be simply implemented on the Google Earth Engine (GEE) platform with a free and available GEE code [36].

In addition to the extraction algorithm of fallowed cropland, accurate and efficient land cover classification techniques are fundamental and essential for obtaining the spatial distribution and extent of the land cover of interest (i.e., cropland). Machine learning algorithms have become promising classification methods owing to their superior generalization capability and robustness. Several machine learning algorithms, such as support vector machines (SVMs), back-propagation neural networks (BP), decision trees (DTs), and random forest (RF), are widely used for land cover classification [44,45]. Random forest, as a tree-based ensemble method, has shown prominent performance among these methods and has a strong capacity for data mining from high-dimensional feature variables [46,47].

Remote sensing (RS) methods are commonly applied to rapidly extract and update ground surface information and geographic information systems (GIS) can provide flexible geographic spatial analysis tools to detect and display spatial hotspots and disperse objects of interest (i.e., active, fallowed, and abandoned cropland) based on their neighborhood [48,49]. In addition, the combination of RS and GIS technology has been widely used in environment-related research, such as land use change, spatial planning, and environmental and socioeconomic risk issues [50–52]. Therefore, in this study, the use of RS and GIS is beneficial for discovering the potential impact of military conflicts, which play a significant role in spatiotemporal change assessment and decision support in agricultural activities.

This study developed a feasible and comprehensive framework for analyzing the spatiotemporal distribution of agricultural land and assessing the impact of the Ukraine–Russia war on agricultural management in Ukraine using RS and GIS technology. Several proven and promising methods have been used to extract land cover information from 2018 to 2022 using RS imagery on the GEE platform. Moreover, the spatial distribution pattern changes in agricultural land use (i.e., active, fallowed, and abandoned cropland) dynamics and the empirical assessment of the war impact on agricultural management status and food security were performed by means of GIS technology. This study provides an accessible methodological framework for conducting regular assessments to monitor the impact of the war on food security and agricultural management. It can be used to estimate the damage during the ongoing war, and is regarded as a mechanism of support for scientific decisions related to restoration planning.

2. Materials and Methods

2.1. Study Area

Ukraine is a country in Eastern Europe (longitude: 31°9′56″ E; latitude: 48°22′46″ N) that covers approximately 603,500 km^2 and has a population of approximately 43 million people. It is divided into 24 oblasts (Cherkasy, Chernihiv, Chernivtsi, Crimea, Dnipropetrovsk, Donetsk, Ivano-Frankivsk, Kharkiv, Kherson, Khmelnytskyi, Kyiv, Kirovohrad, Luhansk, Lviv, Mykolaiv, Odesa, Poltava, Rivne, Sumy, Ternopil, Vinnytsia, Volyn, Zakarpattia, Zaporizhzhia and Zhytomyr) and one autonomous republic (Crimea) (Figure 1) [53]. Ukraine has an average elevation of about 178 m. This region has a typical humid continental climate, with an annual average precipitation of 565 mm and an annual average temperature of 7.1 °C [54]. Ukraine, as an agrarian country, is one of the largest grain exporters in the world, and its major land cover type is cropland, covering nearly half of the country's area. Wheat, corn, soybeans, sunflower, barley, and rapeseed are the main agricultural products [55]. Ukraine regained its independence in 1991, with the dissolution of the Soviet Union. The agricultural land management pattern has shifted from collectivized towards market-oriented economies [9,10]. Large areas of agricultural cropland have been fallowed or abandoned without management because of the lack of financial support, and weeds may regrow on the cropland [23]. In addition to the problems of historical and political volatility, the ongoing Ukraine–Russia war has created the risk of food insecurity. The country's vast agricultural areas are subjected to military occupation, which is not conducive to sowing campaigns. The war zones are shown in Figure 1, and are partitioned according to international military reports and cartographic materials up to June 2022. The affected farming area is approximately 38% of the total cropland area of Ukraine, comprising 232,300 km^2, which is taken into consideration in the buffer zone of the frontline territory.

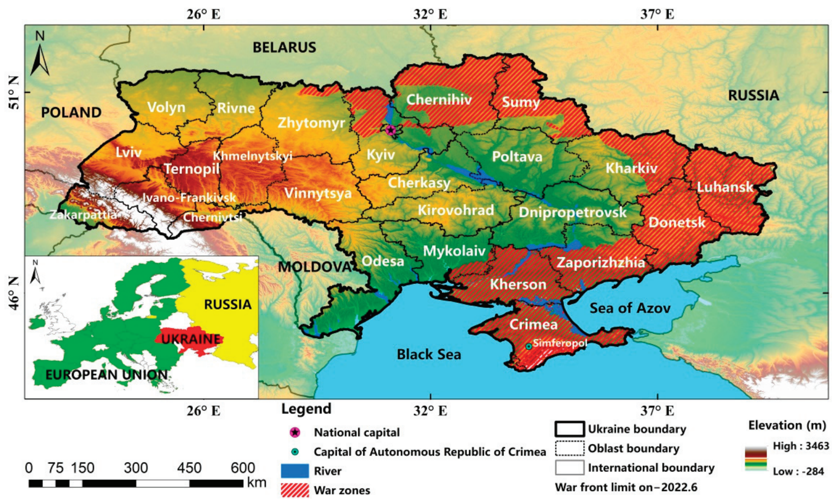

Figure 1. Study region map of Ukraine with respect to war zones and elevation.

2.2. Remote Sensing Satellite Imagery

Surface reflectance (SR) images from the Landsat 8 Operational Land Imager (OLI) (Collection 2, level-2) were collected from the GEE cloud computing platform from 2018 to 2022. Landsat 8 SR products have been atmospherically corrected using the Land Surface Reflectance Code (LaSRC). Clouds, cloud shadows, snow, and ice pixels were masked based on the accompanying quality assessment band. The surface reflectance values from Landsat collection 2 were calculated by multiplying the original pixel value by a scale factor of 0.0000275, and then adding an offset of −0.2 per pixel. To obtain clear and cloudless images that cover the entire study area, we filtered out Landsat images acquired from April to October 2018 to 2021, and March to June 2022.

2.3. Methodological Framework

The methodology was carried out in two phases (Figure 2). First, level-1 land cover (cropland, forest, grassland, bare ground, built-up area, water, and wetland) was classified using an RF classifier with several feature variables derived from Landsat images, such as spectral indices, tasseled cap transform variables, and gray-level co-occurrence matrix texture (GLCM) variables. Five level-1 land cover classification maps were generated for the years 2018–2022. Within the cropland extent, the FANTA method was applied to map annual fallowed cropland using a high-quality NDVI time series with a 30 m spatial resolution produced by the GF-SG method by integrating Landsat and MODIS images. The abandoned cropland was extracted using two consecutive years of fallowed cropland maps. In the first phase, we used several RS algorithms to extract information on objects of interest (land cover types, fallowed cropland, and abandoned cropland) on the GEE platform. Second, we analyzed the spatial and temporal changes in agricultural croplands and assessed the impact of the ongoing Ukraine–Russia war on agricultural management practices and food security. In the second phase, we introduced the kernel density spatial analysis technology of GIS to more clearly reveal the spatial distribution pattern.

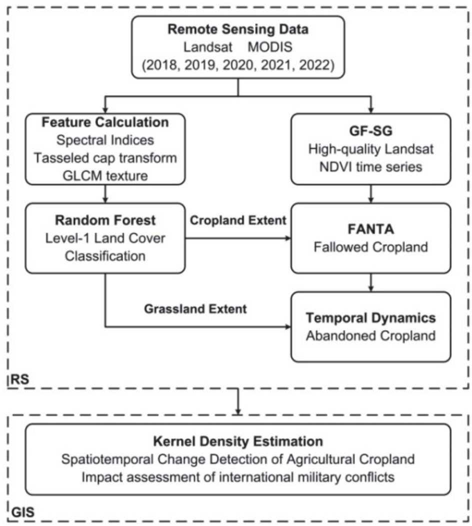

Figure 2. Flowchart of mapping agricultural land, analyzing the spatiotemporal change of agricultural cropland and assessing the war impact.

2.4. Level-1 Land Cover Classification

2.4.1. Training and Testing Sample Generation

To efficiently obtain accurate and sufficient training samples, we integrated manually labeled samples and samples automatically derived from a global land cover product. Liu et al. proposed a novel global 30 m land cover dataset that provided fine and accurate classification maps once every 5 years from 1985 to 2020 (GLC_FCS30-1985_2020) [56]. The global land cover classification product is produced by applying an RF classifier based on time series Landsat surface reflectance data, Sentinel-1 SAR data, DEM data, a global thematic auxiliary dataset, and a prior knowledge dataset on the GEE platform [56–58]. We adapted the fine classification system of the GLC_FCS30-1985_2020 product to be consistent with the level-1 land cover types of Ukraine owing to the actual geographical characteristics (Table 1).

Table 1. Number of samples and description of class system for initial land cover classification in Ukraine.

No.	Code	Class	Training Samples			Testing Samples
			P	M_{2018}	M_{2021}	
1	C1	Bare ground	1975	834	867	169
2	C2	Built-up area	1994	1609	1611	279
3	C3	Cropland	5002	1791	1796	322
4	C4	Forest	4975	1756	1763	116
5	C5	Grassland	2134	1106	922	271
6	C6	Wetland	1507	1376	1389	193
7	C7	Water	1811	639	634	225
	Total		19,398	9111	8982	1575

P represents the training samples derived from land cover classification product data; M represents the training samples generated by manually labeling.

We extracted the stable pixels for which the land cover classes remained unchanged from all the GLC_FCS30-1985_2020 classification maps by using the overlay spatial analysis method in ArcGIS 10.2 software (ESRI Inc., Redlands, CA, USA). Subsequently, many points were automatically generated using stratified random sampling from the stable areas. Considering the influence of the classification errors of the product, we checked the automatically derived points and removed the observably incorrect points according to Google Earth and Landsat images. A total of 19,398 points were selected from the classification product as the training samples for classification in each year. Considering the labor cost, operational efficiency, and dynamic spatial distribution of land cover across several years, we manually labeled a total of 9111 and 8982 points from the Landsat images in 2018 and 2019, respectively, and labeled points of other years could be updated based on the two-year sample sets.

A total of 1575 points within the testing dataset used to assess the classification accuracy were manually labeled from the high-resolution images available on Google Earth. Moreover, to ensure the reliability of the testing data for assessing the historical classification results, the global ESRI land cover classification product with a 10 m spatial resolution for each year from 2017 to 2021 released by the Environmental Systems Research Institute was used as a reference to correct the testing points.

2.4.2. Random Forest Classification

The random forest classifier is an ensemble learning algorithm that integrates many classification and regression tree (CART) classifiers by using a bagging strategy. The bootstrap sampling technology is used to generate sample subsets for training each CART. During the construction of a CART, each node is split using the feature variables based on the threshold yielded from the smallest Gini coefficient [59,60]. The RF method has been widely used and proved to perform better with high-dimensional data and provide higher accuracy in classification tasks [61,62]. Furthermore, application programming interfaces (APIs) for the RF classifier have been provided to make requests to the GEE servers, allowing for the rapid completion of large-scale land cover mapping on the GEE platform. The number of decision trees (N_{tree}) and the number of variables per split (M_{try}) are important hyper-parameters of the RF classifier that can affect computational efficiency and classification accuracy. In this study, N_{tree} was set to 100 and the value of M_{try} was the square root value of the total number of input features.

We applied the RF method with several feature variables to classify level-1 land covers. The variables included surface reflectance variables derived from Landsat images (blue, green, red, near infrared, and two shortwave infrared bands); Normalized Difference Vegetation Index (NDVI), Modified Normalized Difference Water Index (MNDWI), Normalized Difference Built-up Index (NDBI), and Bare Soil Index (BSI); brightness, greenness, and wetness from a tasseled cap transform (Table 2); and texture variables (contrast, correlation, inverse difference moment, sum average, and entropy) calculated from the gray-level co-occurrence matrix method (GLCM) using the near-infrared band that can reflect vegetation information [63–65].

Table 2. Calculation equations of normalized difference indices and component variables from tasseled cap transform method.

Abbreviation	Formula
NDVI	(NIR − Red)/(NIR + Red)
MNDWI	(Green − SWIR1)/(Green + SWIR1)
NDBI	(SWIR1 − NIR)/(SWIR1 + NIR)
BSI	((SWIR2 + Red) − (NIR + Blue))/((SWIR2 + Red) + (NIR + Blue))
Brightness	0.3037 × Blue + 0.2793 × Green + 0.4743 × Red + 0.5585 × NIR × +0.5082 × SWIR1 + 0.1863 × SWIR2
Greenness	−0.2848 × Blue − 0.2435 × Green − 0.5436 × Red + 0.7243 × NIR × +0.0840 × SWIR1 − 0.1800 × SWIR2
Wetness	0.1509 × Blue + 0.1973 × Green − 0.3279 × Red + 0.3406 × NIR × −0.7112 × SWIR1 − 0.4572 × SWIR2

Because of the pixel-based classification, the results may contain many scattered pixels representing misclassified pixels that directly decrease the classification accuracy and impact the continuity of spatial patterns for land cover types in the classification maps. Therefore, a post-classification process was conducted to reduce the salt-and-pepper noise in ENVI 5.1 software (Exelis Visual Information Solutions, Inc., Boulder, CO, USA). Noise pixels were removed using majority analysis, which groups the scattered pixels into the majority class within a 5 × 5 kernel size.

2.4.3. Accuracy Assessment

The confusion matrix is one of the most common methods applied to assess classification accuracy. Several evaluation indicators derived from the confusion matrix can be used to comprehensively assess the classification results, including the overall accuracy (OA), kappa coefficient (Kappa), user's accuracy (UA), and producer's accuracy (PA). The OA represents the total percentage correctly classified. The kappa coefficient reflects the agreement between the classification results and the actual reference data. The UA describes the percentage of correctly classified results of the classification results per class. The PA describes the percentage of correctly classified results of the actual reference sites per class [66]. The equations for calculating each indicator are as follows:

$$\mathrm{OA} = \sum_{i=1}^{n} m_{ii}/N \tag{1}$$

$$\mathrm{UA} = m_{ii}/m_{i+} \tag{2}$$

$$\mathrm{PA} = m_{ii}/m_{+i} \tag{3}$$

$$\mathrm{Kappa} = \left(N\sum_{i=1}^{n} m_{ij} - \sum_{i=1}^{n} m_{i+}m_{+i}\right)/\left(N^2 - \sum_{i=1}^{n} m_{i+}m_{+i}\right) \tag{4}$$

where N is the total number of testing samples; m_{ii} is the correctly classified pixel of class i; m_{i+} is the total pixel number of class i in the data to be verified; m_{+i} is the total pixel number of type i in the reference data; and n is the class number.

2.5. Fallowed Cropland Classification

2.5.1. NDVI Time Series Reconstruction Method

The Landsat NDVI time series data with 30 m spatial resolution effectively reflected the vegetation phenological stages and could be used to classify croplands under different management practices [67,68]. However, due to frequent cloud contamination, unscanned gaps, and limitations of satellite 16-day revisit cycles, temporally continuous Landsat NDVI time series were difficult to obtain.

A novel reconstruction method called gap filling and Savitzky–Golay filtering (GF-SG) was recently proposed by Chen, and was used to produce Landsat NDVI time series data in this study. The GF-SG method first fills the missing values of the original Landsat NDVI time series data by using MODIS NDVI time series data to generate a cloud-free Landsat NDVI time series. The coarse spatial resolution of MODIS images is resampled using the bicubic interpolation method, which is in accordance with the spatial resolution of the Landsat images. The temporal shape curve for each Landsat image pixel is determined by searching and matching operations in the resampled MODIS image around the pixel location. The synthesized Landsat-MODIS NDVI time-series data are preliminarily generated. Second, a weighted Savitzky–Golay filter method is designed to remove residual noise and smooth the synthesized NDVI time series. Finally, cloud-free and temporally continuous Landsat NDVI time series data with 30 m spatial resolution and an 8-day period are produced [36].

Additionally, we selected the MOD09Q1 product from the GEE platform to generate MODIS time series data. MOD09Q1, corrected for atmospheric conditions, provides surface spectral reflectance of red and near-infrared at 250 m resolution. For each pixel, a value was selected from all acquisitions within the 8-day composite period. Moreover, the GF-SG method can be implemented simply using an open-source GEE code on the GEE platform.

Finally, we calculated 46 NDVI images for each year from 2018 to 2021 and 28 NDVI images for January–July 2022.

2.5.2. FANTA Algorithm

The fallow-land algorithm based on neighborhood and temporal anomalies (FANTA) method is used to identify active and fallow land by using NDVI time series data, which compares the current greenness of a cropland pixel to its historical greenness and its neighborhood greenness [31,32]. Temporal anomalies ($T\_NDVI^m_{max}$ and $T\_NDVI^m_{range}$) are calculated using a z-score transformation as follows:

$$T\_NDVI^m_{max} = \left(NDVI^m_{max} - NDVI^m_{max\_mean}\right)/NDVI^m_{max\_stdv} \quad (5)$$

$$T\_NDVI^m_{range} = \left(NDVI^m_{range} - NDVI^m_{range\_mean}\right)/NDVI^m_{range\_stdv} \quad (6)$$

where m is the month in the year of interest; $NDVI^m_{max}$ is the monthly NDVI maximum value; $NDVI^m_{range}$ is the monthly NDVI range value that is the difference between the maximum and minimum NDVI values. The mean, standard deviation and median values of monthly $NDVI^m_{max}$ and $NDVI^m_{range}$ are also calculated. In particular, the monthly $NDVI^m_{max}$ and $NDVI^m_{range}$ values used for calculating mean and standard deviation are greater than or equal to the median NDVI observed with the pixels between 2018 and 2022.

Spatial anomalies are calculated using z-score transformation based on the monthly NDVI maximum and monthly NDVI ranges, similar to the temporal anomalies. However, the extraction method of the median values ($S\_NDVI^m_{max\_stdv}$ and $S\_NDVI^m_{ramge\_stdv}$) is different, and was calculated based on all annual pixels within a neighborhood zone. In this study, the administrative regions are used as spatial neighbor regions instead of climate divisions from the primal method because of the aim of identifying the war-driven agricultural management changes in our study.

The FANTA method uses monthly NDVI temporal and spatial anomalies to identify the fallowed cropland based on four logical statements (Equations (7)–(10)). If any two of the four logical statements were true, the pixel was classified as fallowed cropland for a given month.

Statement 1 (Equation (7)) and Statement 2 (Equation(8)) illustrate the consistently low NDVI maximum and range values of fallowed cropland, respectively, during the growing season based on temporal greenness anomalies.

$$T\_NDVI^{m_i}_{max} < -3(i = 5, 6, 7) \text{ OR } T\_NDVI^{m_j}_{max} < -3(j = 4, 5, 6) \quad (7)$$

$$T\_NDVI^{m_i}_{range} < -3(i = 5, 6, 7) \text{ OR } T\_NDVI^{m_j}_{range} < -3(j = 4, 5, 6) \quad (8)$$

where m is the month in the year of interest; $T\_NDVI^m_{max}$ and $T\_NDVI^m_{range}$ are the temporal anomalies based on the NDVI maximum and range values, respectively; i represents the main growing season in May, June, and July; and j represents the early growing season in April, May, and June.

Statement 3 (Equation (9)) and Statement 4 (Equation (10)) illustrate the consistently low NDVI maximum and range values of fallowed cropland within a neighborhood, respectively, during the main growing season based on spatial greenness anomalies.

$$\text{MAX}\left(NDVI^{m_i}_{max}\right) < 0.8\text{MAX}\left(S\_NDVI^{m_i}_{max\_stdv}\right)(i = 4, 5, 6, 7) \quad (9)$$

$$\text{MAX}\left(NDVI^{m_i}_{range}\right) < 0.8\text{MAX}\left(S\_NDVI^{m_i}_{range\_stdv}\right)(i = 4, 5, 6, 7) \quad (10)$$

where $S\_NDVI^m_{max\_stdv}$ and $S\_NDVI^m_{ramge\_stdv}$ are the median values of $NDVI^m_{max}$ and $NDVI^m_{range}$ that are calculated based on all annual pixels within a neighborhood zone, respectively; i represents the main growing season in April, May, June, and July.

2.6. Cropland Spatial Distribution Analysis

To reveal the spatial distribution pattern of active, fallowed, and abandoned croplands more clearly and visually, a spatial geographical analysis algorithm called kernel density estimation was applied. This method calculates the density of point features in a neighborhood around those features, and produces a continuous density surface map to show the density of objects of interest. This method is beneficial for detecting and displaying spatial hotspots and the dispersion of cropland for effectively and directly understanding spatial and temporal pattern characteristics [69,70]. In this study, the kernel density method was carried out using spatial analysis tools in ArcGIS 10.2 software. First, the raster data obtained from several fallowed and abandoned cropland classification maps were converted to polygon vector data. Then, the center points of the polygon features were extracted to execute the kernel density method. Finally, kernel density maps were obtained to assess agricultural management in the case of the ongoing Ukraine–Russia war.

3. Results

3.1. Level-1 Land Cover Classification

The RF method was applied to classify level-1 land cover types within 18 variables for each year from 2018 to 2022. The overall accuracy, kappa coefficient, producer's accuracy, and user's accuracy are shown in Table 3. The overall accuracy and kappa coefficient of annual land cover classification are similar, with values greater than 80% and 0.79, respectively. The RF method yielded the highest producer's accuracy and user's accuracy for bare ground, built-up areas, and water, approximately above 90% for each year. Forests had the highest producer's accuracy with above 95%, whereas the user's accuracy value was lower, ranging from 69.62 to 86.05%. RF also produced good results for the cropland used to extract the agricultural extent. The producer's accuracy of cropland ranged from 86.02 to 92.55%, and the user's accuracy of cropland ranged from 67.95 to 71.99%. In contrast, grasslands and wetland had lower accuracies among all classes. The producer's and user's accuracies of grassland were about 80% and 50%, respectively, and the classification accuracy of wetland was approximately 70%.

Table 3. Accuracy evaluation results based on testing samples.

Year		C1	C2	C3	C4	C5	C6	C7	OA(%)	Kappa
2018	PA(%)	97.63	94.62	88.20	98.28	44.65	65.80	98.22	82.29	0.7904
	UA(%)	94.83	91.03	70.12	75.00	79.08	70.56	100.00		
2019	PA(%)	88.76	91.40	87.58	98.28	53.14	60.10	99.56	81.59	0.7817
	UA(%)	97.40	89.47	67.95	79.17	78.26	68.64	100.00		
2020	PA(%)	84.02	95.70	86.02	98.28	47.97	58.03	97.78	80.13	0.7646
	UA(%)	96.60	87.25	68.23	70.81	80.25	65.12	99.55		
2021	PA(%)	85.80	95.70	90.99	95.69	55.72	77.20	98.22	84.89	0.8208
	UA(%)	96.03	89.90	71.99	86.05	90.42	74.13	99.10		
2022	PA(%)	81.66	96.42	92.55	94.83	57.35	66.84	98.22	83.82	0.8081
	UA(%)	96.50	96.42	69.46	69.62	88.14	79.14	97.36		

Figure 3 shows the visual spatial patterns of all classes based on Google Earth images, RF classification results (CR_RF30-2021), and three different land cover products. The products included GLC_FCS with 30 m spatial resolution in 2020 (GLC_FCS30-2020), GlobeLand with 30 m spatial resolution in 2020 (GlobeLand30-2020), and ESRI land cover data with 10 m spatial resolution in 2021 (ESRI10-2021). The results revealed that CR_RF30-2021 achieved desirable visual results, as demonstrated in the second column of Figure 3, which were able to better distinguish different classes within the neighborhood. The class boundaries were smooth and clear. The spatial continuity was less influenced by the scattered pixels (salt-and-pepper noise). Compared with the GLC_FCS30-2020 and GlobeLand30-2020 products, CR_RF30-2021 showed better visual classification results for bare ground, grassland, and wetland (see Figure 3b,c). Although cropland, as the most focused class, was partially misclassified as grassland and wetland, the classification results were satisfactory and can be sufficient to illustrate the actual spatial pattern compared with the high-spatial-resolution maps.

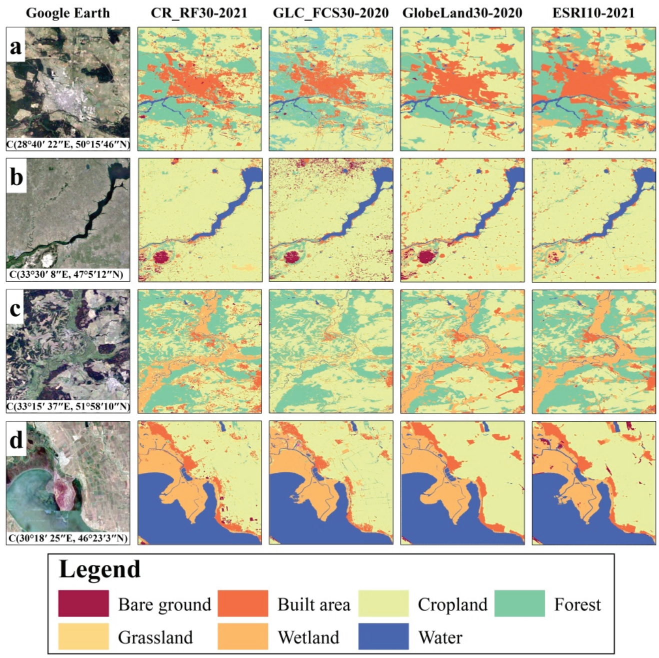

Figure 3. Four representative subsets (**a**–**d**) for comparing the RF classification results with three land cover products and Google Earth images. The first column shows the Google Earth image, the second column shows the RF classification results named CR_RF30-2021, the following columns illustrate the classification products named GLC_FCS30-2020, GlobeLand30-2020, and ESRI10-2021. C (longitude, latitude) represents the central geographic coordinate of the enlarged pictures.

3.2. Spatial and Temporal Analysis of Fallowed and Abandoned Cropland

Fallowed cropland, defined as farmland without cultivation and management for one year, was extracted from the FANTA method. To monitor the abandoned cropland, we used fallowed cropland time series classification results to map the abandoned cropland in which the cultivatable land was not cultivated for at least two consecutive years.

Figure 4 shows that the fallowed cropland was widespread in many administrative regions, and the distribution pattern varied during the five years. The percentage of fallowed croplands fluctuated between years. The fallowed cropland was mainly concentrated in eastern Ukraine, and the highest density frequently occurred in Kherson, which accounted for 12.49–43.43% of the total fallowed cropland area of Ukraine from 2018 to 2022. Other eastern regions, such as Zaporizhzhia, Crimea, Luhansk, Kirovohrad, Dnipropetrovsk, and Mykolaiv had larger areas of fallowed croplands with an area percentage of more than 6% of total fallowed cropland for at least two years. In western Ukraine, the spatial distribution pattern of fallowed cropland was dispersed with a smaller area percentage of less than 4%. Some western regions, such as Zhytomyr, Volyn, Rivne, Lviv, and Khmehnytskyi, accounted for more than 1% of the total fallowed cropland area. The fallowed cropland area percentage of total cropland area in each administrative region was 0.01–3.84%.

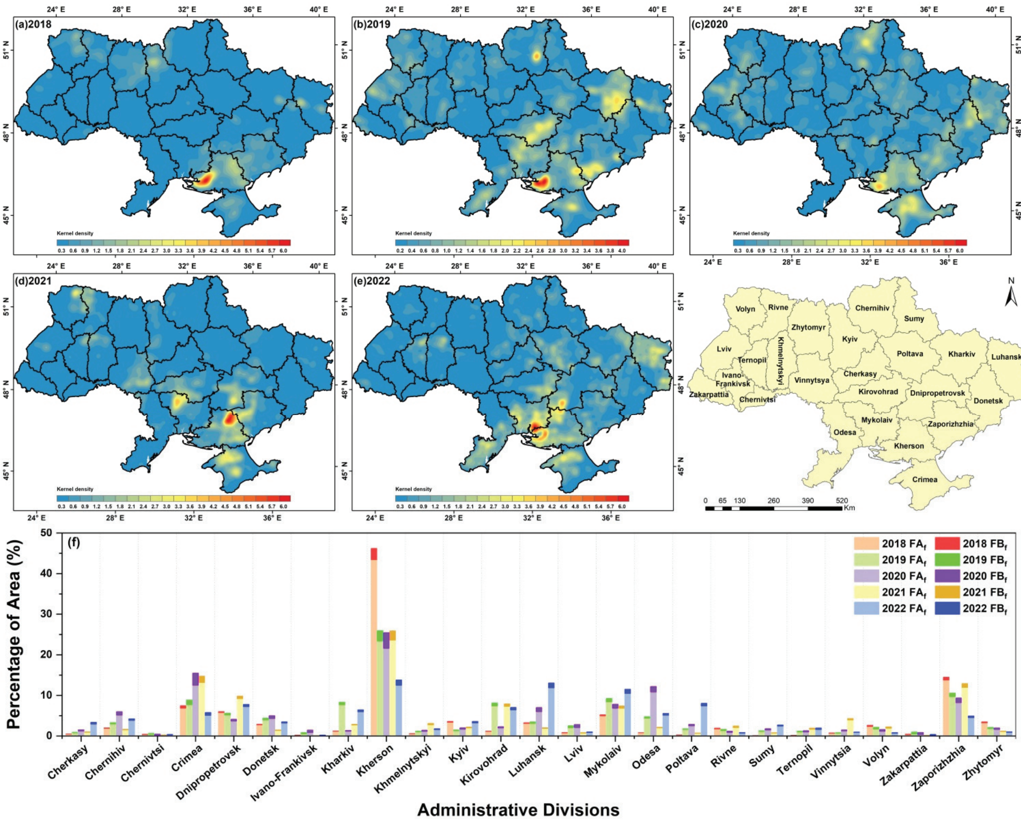

Figure 4. (**a**–**e**) illustrate the annual kernel density maps of fallowed cropland from 2018 to 2022; (**f**) illustrates the statistical graph of area percentage of fallowed cropland. FA_f represents the area of fallowed cropland in each administrative region as a percentage of the total fallowed cropland area in Ukraine. FB_f represents the area of fallowed cropland as a percentage of the cropland area in each administrative region.

Figure 5 shows that a certain area of fallowed cropland without management changed to abandoned croplands and occurred in several administrative regions with different area percentages. The hotspots frequently occurred in western Kherson, with the area percentage of total abandoned cropland varying from 24.62 to 64.39%, and also continually arose in the center of Luhansk, with the area percentage varying from 0.75 to 14.42%. Moreover, the abandoned cropland was distributed more widely in eastern Ukraine from 2021 to 2022; besides Kherson and Luhansk, some administrative regions, such as Crimea, Donetsk, Mykolaiv, and Zaporizhzhia, also had large areas of abandoned cropland, with an area percentage of more than 7% of total abandoned cropland. Abandoned cropland is also widely distributed in some regions in the northwest of Ukraine, such as Volyn, Rivne, Zhytomyr, and Kyiv, during different periods.

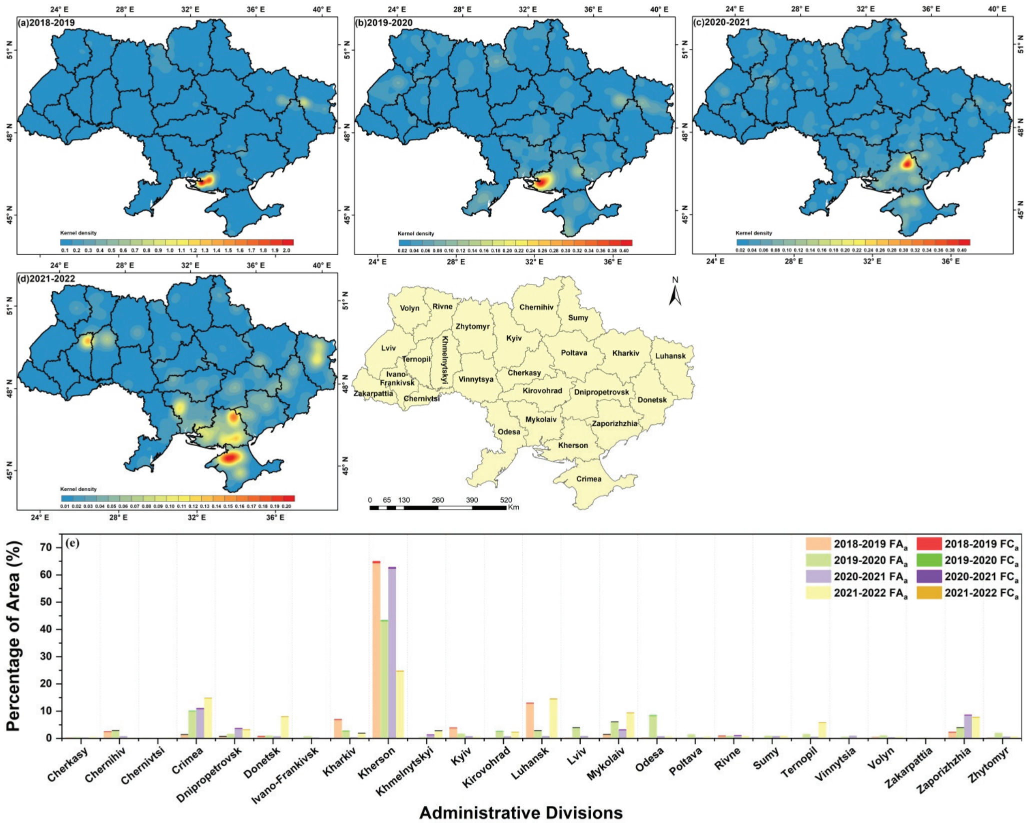

Figure 5. (**a**–**d**) illustrate the kernel density maps of abandoned cropland for each consecutive two-year period from 2018 to 2022; (**e**) illustrates the statistical graph of area percentage of abandoned cropland. FA_a represents the area of abandoned cropland in each administrative region as a percentage of the total abandoned cropland area in Ukraine. FC_a represents the area of abandoned cropland as a percentage of the total fallowed cropland area in each administrative region.

3.3. Influence of the War on Agricultural Cropland

As for the influence analysis of the war on agricultural development and management, farmland that was regularly cultivated for at least three years during 2018–2021 and only fallowed in 2022 was defined as cropland that could be severely impacted by the Ukraine–Russia war. Administrative regions that suffered from the war mainly included Chernihiv, Crimea, Donetsk, Kharkiv, Kherson, Kyiv, Luhansk, Mykolaiv, Sumy, Zaporizhzhia, and Zhytomyr, which had large areas of cropland (Figure 6b). From the kernel density map, within the confines of war zones, the agricultural management of cropland was influenced to various extents, with fallowed cropland distributed widely in all administrative regions. Western Kherson, the center of Luhansk and northern Crimea had high kernel density values, with largest area percentages of 25.35%, 22.91%, and 9.13% of the total fallowed cropland, respectively. Other administrative divisions, such as Mykolaiv, Chernihiv, Kharkiv, Zaporizhzhia, and Donetsk, had an area percentage of the total fallowed cropland with the value of approximately 6%. The fallowed cropland area percentage of total cropland area in each administrative region was 0.17–2.14%.

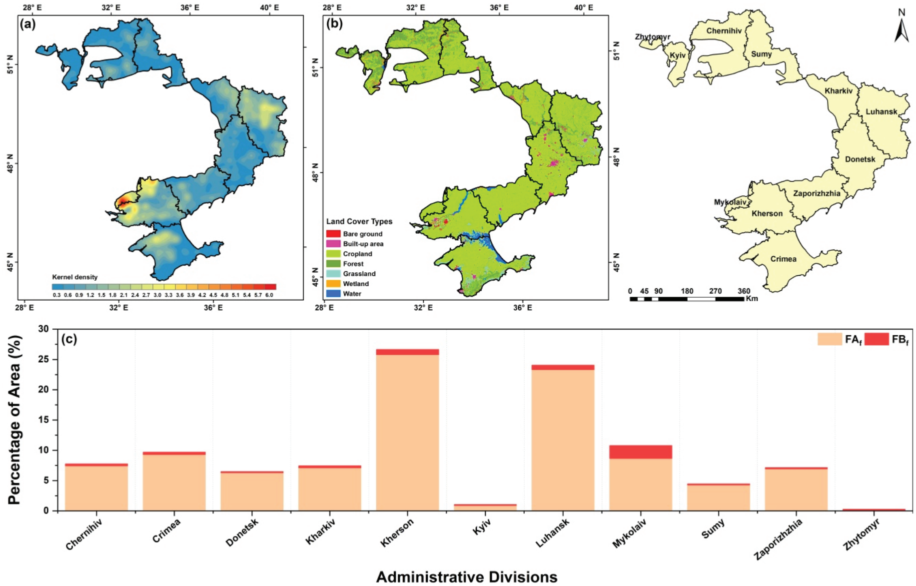

Figure 6. (**a**) illustrates the kernel density map of fallowed cropland in war zones; (**b**) illustrates the level-1 land cover classification map of the war zones; (**c**) illustrates the statistical graph of area percentage of fallowed cropland. FA_f represents the area of fallowed cropland in each administrative region as a percentage of the total fallowed cropland area in war zones. FB_f represents the area of fallowed cropland as a percentage of the cropland area in each administrative region.

4. Discussion

4.1. Mapping and Analysis Approaches

To accurately and rapidly extract fallowed and abandoned land and effectively assess the influence of the war on agricultural cropland management practices in Ukraine, we applied a series of proven remote sensing and GIS techniques, including the RF classifier, GF-SG method, FANTA algorithm, and kernel density estimation; these remote sensing methods can be implemented on the GEE platform. The reasonable results adequately demonstrate the accessibility of these methods for monitoring large-scale cultivated land management patterns.

For the RF method to classify level-1 land cover types, several variables were used to provide abundant information, which helped identify the spectral, geometric, interior structure, and spatial neighborhood characteristics of different surface ground objects on Landsat 8 RS imagery. The RF classifier with these variables produced satisfactory classification accuracy for cropland, which played an important role in developing a cultivated mask layer for the following tasks. In the annual classification maps, cropland was partially misclassified as grassland and wetland owing to the spectral similarity of herbaceous vegetation and the spatially blurred boundary of adjacent classes.

The FANTA algorithm mainly depends on NDVI time series data to identify fallow land. The most prominent advantage of the FANTA algorithm is that it requires no field data for training and instead relies adequately on temporal and spatial NDVI anomalous values [31]. Using this method to map fallowed croplands is not subject to geographical conditions, climate conditions, or time cost; it may help factually reflect the historical greenness dynamics of vegetation growth and rapidly obtain estimate results to monitor the agricultural cultivated management status. The GF-SG method significantly reduced the influence of cloud contamination on Landsat images and improved the temporal resolution, resulting in high-quality Landsat NDVI time series data with 30 m spatial resolution and 8-day temporal resolution based on MODIS data [36].

Kernel density estimation is a suitable spatial analysis technology for detecting hotspots and dispersion patterns in fallowed and abandoned croplands. It can intuitively and visually reveal the areas that frequently occur as hotspots of fallowed and abandoned croplands, which should be considered for reinforcing agricultural management and increasing agricultural production [71]. The hotspots of fallowed and abandoned cropland sequentially occurring in war zones can be used as an indicator for assessing the risk of food crisis caused by the war.

A joint utilization of the RF classifier, GF-SG method, FANTA algorithm, and kernel density estimation proved beneficial for quickly monitoring and assessing agricultural cropland status in large-scale regions where it was difficult to conduct fieldwork. The practical international situation of the ongoing war in Ukraine is complicated and volatile, which increased the risk of collecting field data, and we had minimal detailed prior knowledge of Ukrainian agricultural management. The methods and implementation procedures proposed in this study can be used for the rapid and effective assessment of the impact of war on agricultural management.

4.2. Assessment of Agricultural Cropland Management Practices

The annual kernel density maps of fallowed cropland illustrated that fallow cropland management was common in Ukraine. The spatial distribution pattern of fallowed croplands was widespread and varied between years. Hotspots of fallowed cropland frequently occurred in eastern Ukraine, such as Kherson, Crimea, Luhansk, and Zakarpattia, and long-term consecutive fallow agricultural management caused cropland abandonment. Moreover, Volyn, Rivne, Zhytomyr, Kyiv, and Chernihiv, which were located in northwest Ukraine, also had widely distributed abandoned croplands.

Owing to a more direct evaluation of the influence of the war in Ukraine, we further extracted the cropland that was regularly cultivated for at least three years from 2018 to 2021 but just fallowed in 2022. The results revealed that the hotspots of cropland that were impacted by the war were found in western Kherson, the center of Luhansk, and northern Crimea. Kherson and Luhansk are the major war zones where Russian forces controlled or operated attacks without control from February to July 2022. The Autonomous Republic of Crimea is the only region within Ukraine with its own constitution. It came to be controlled by Russia on 16 March 2014, and had a sovereignty dispute between Russia and Ukraine [72]. Northern Crimea was close to the war zones of Russian control. Other oblasts, such as Zaporizhzhia, Donetsk, and Kharkiv in eastern Ukraine, and Chernihiv, Sumy, Kyiv, and Zhytormyr in northern Ukraine, had large areas of fallowed cropland, which also suffered from the Ukraine–Russia war and Ukrainian partisan warfare, which have directly affected the agricultural and economic activities of Ukraine [73].

It has been reported by FAO that these war-impacted oblasts have suffered from the highest levels of food insecurity, especially Kherson, Luhansk, Kharkiv, Chernihiv, and Sumy. The war has severely disrupted economic activities, which has caused a loss of income and increased food prices. Due to migration movement and agricultural infrastructure damaged by the ongoing war, agricultural productivity has significantly reduced and a large area of cultivatable land has become fallowed cropland without agricultural management [74]. With intensifying wars, pollutants from ordnance material explosions can seriously destroy soil, water, and the atmospheric environment, which directly influences the growth of crops and food production.

As Ukraine is one of the world's top agricultural producers and exporters, the war could jeopardize the food security of many countries, especially those that are highly dependent on Ukraine and Russia for food and fertilizer imports [75]. Moreover, according to the historical fallowed and abandoned cropland maps, the spatial distribution of agricultural croplands without management is widespread in many oblasts and varies during different periods based on various factors such as soil quality, topography, population, climate, and agricultural and economic policies [76]. It is necessary to monitor agricultural resources and management regularly to reduce the risk of a food crisis.

5. Uncertainty and Limitations

Our study has demonstrated that the proposed methodological framework for analyzing the spatiotemporal distribution of agricultural land and assessing the impact of war on agricultural management is effective and feasible. The evaluated results can be used to support scientific assessments and decisions for food security and agricultural livelihoods. Nevertheless, some uncertain and limiting factors may impact the results, and several avenues for further improvement of these methods are possible.

First, we emphatically assessed agricultural cropland management practices from 2018 to 2022, in which the time span was comparatively shorter for cropland abandonment mapping. The extension of the evaluated period and longer-term NDVI time series data may provide more sufficient and accurate historical greenness information for cultivated land. The FANTA method can improve the identification precision of fallowed croplands. Second, owing to the limitations of geographical conditions, the lack of field data creates uncertainty in the evaluation accuracy. Actual field data on agricultural management and auxiliary data, such as soil maps, agricultural parcel abandonment rate maps and historical agricultural statistical data, can help to reduce misinterpretations of cropland management maps. Moreover, the FANTA method depends mainly on long-term statistical NDVI values with empirical parameters. Auxiliary data can be used to correct the empirical parameters to reveal the actual ground conditions more accurately. Third, the quality of Landsat imagery plays an important role in the extraction of information. Although NDVI interpolation methods effectively reduce the impact of cloud contamination, they may not completely eliminate noise. The use of multisensory data may provide additional information to ensure data accuracy. We will continue to conduct this research. If we have the opportunity to request a future partnership with Ukrainian universities in connection with the agricultural sector, we may be able to obtain accurate materials from local farmers or experts and make the results as accurate as possible.

6. Conclusions

This study proposes a feasible framework for monitoring the spatiotemporal distribution of agricultural land and assessing the impact of war on agricultural management in Ukraine using RS and GIS technology. RF, GF-SG, and FANTA algorithms were used to classify fallowed croplands based on Landsat time series data on the GEE platform. Abandoned croplands were extracted based on the change detection. The kernel density method can help clearly reveal the spatial distribution of fallowed and abandoned croplands. The successful utilization of these methods has proven beneficial for the simple and quick monitoring of the spatiotemporal characteristics of agricultural cropland status in large-scale regions where it is difficult to conduct fieldwork. The results reveal the serious negative influence of war on agricultural management and development, which can directly increase the risk of international food insecurity. This study provides an insightful way to utilize scientific technology to regularly monitor the impact of war on food security and agricultural livelihoods. It can be easily expanded to other places dealing with similar issues which could be of concern to the whole world, e.g., wars, territorial conflicts based on irredentism, or more general global changes impacting agricultural developments and their regulation factors in the future.

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What Makes Farmers Aware in Adopting Circular Bioeconomy Practices? Evidence from a Greek Rural Region

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Abstract: Action 2 of the European Union's Updated Bioeconomy Strategy, i.e., "Deploy local bioeconomies rapidly across Europe", promotes education and training in all member states. It is a fact that Greece has not yet adopted a national bioeconomy strategy, so stakeholders and farmers cannot benefit from its potential. The adoption of bioeconomy practices is now a prerequisite for receiving funding under the Common Agricultural Policy 2023–2027. Farmers unknowingly use some bioeconomy practices on their farms, and in this study, an attempt was made to investigate how farmers in the region of Western Macedonia would like to be trained in respect of the bioeconomy, knowing the opportunities it offers. The research was conducted through a structured questionnaire answered by 412 farmers from the region. The findings from the subsequent k-means cluster analysis show that farmers can be classified into three clusters: engaged, restricted, and partially engaged. The perceptions that predominate in each cluster are influenced by age, income, and the regional unit in which the farmers reside. In addition, the decarbonization of the Western Macedonia region influences their views and how they would like to be informed about opportunities arising from the bioeconomy. Limitations in this study include the fact that the sample consists only of farmers living and operating in a particular region. In addition, there is an urgent need for political will to establish a national strategy for the bioeconomy. The importance of the present study lies in the fact that few studies have addressed the training of farmers on bioeconomy issues either in Greece or internationally.

Keywords: bioeconomy; training; farmers; bioeconomy practices; regional approach; k-means cluster analysis; Western Macedonia region

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1. Introduction

Strategies for the bioeconomy promote farmer training because educated and skilled farmers are essential to the growth and success of the sector [1–3]. The role of farmers in the production of bio-based products and the adoption of sustainable agriculture practices is critical, and providing them with training and education is necessary to ensure they are equipped to meet the demands of the expanding bioeconomy [4]. To train farmers in respect of the bioeconomy, they need to be educated on the principles and practices of the efficient and sustainable use of biological resources for the production of various products such as food, energy, and materials. This includes teaching them about the latest advancements in biotechnology, agroforestry, precision agriculture, and regenerative farming [5]. Additionally, they should be trained on the economic and business aspects of the bioeconomy, including marketing, branding, and product development [6]. The aim of this training is to empower farmers to play a critical role in the transition towards a more sustainable and resilient future.

The bioeconomy in agriculture has a significant impact on production factors, natural resources, and their potential [7]. The purpose of production factors is to create a favorable environment for the growth and development of farms, influenced by both internal and external variables. Land, the primary production factor in agriculture, determines the productive potential of a farm through its resources [8]. An outdated belief is that land efficiency is related to farm size, but bioeconomics refutes this by linking land efficiency to the farming practices used. Land quality affects production costs, establishes regional comparative advantages, shapes regional structure, and affects the competitiveness of agriculture [9]. The bioeconomy in the agricultural sector generates income comparable to other sectors of the economy, provides the financial resources necessary for modernization, promotes food self-sufficiency, preserves the productive potential of the soil, implements efficient use of agricultural land, reduces environmental risks, and contributes to the production of raw materials with desired quality specifications [10–12].

Sustainable agriculture adheres to the principles of the bioeconomy and ensures that future generations have access to natural resources. It provides opportunities for farmers and the region, enhances quality of life, conserves diversity, offers high-quality employment, emphasizes innovation and education, and fosters social unity through equal opportunities [13,14]. Sustainable agriculture is the definitive solution to the challenges facing the agricultural sector. The utilization of natural resources must be managed in a way that uses renewable resources without depleting or reducing their usefulness [14,15].

Given the above considerations, bioeconomy policies concentrate on training stakeholders, citizens, and farmers on bioeconomy issues [3,16]. In terms of training, stakeholders play an active role in documenting available data sources and identifying gaps in data collection that are crucial for implementing this practice [17]. This will enable the collection and utilization of all existing data by relevant public organizations, which are essential for establishing indicators to monitor training performance [18]. The engagement of these stakeholders is expected to significantly contribute to the overall implementation of the Sustainable Development Goals (SDGs) as outlined in the 2030 Agenda for Inclusive Education [19,20].

In Greece, efforts are also underway to promote the bioeconomy, specifically in the Western Macedonia region. The Cluster of Bioeconomy and Environment of Western Macedonia (CluBE) is working towards the establishment of a bioeconomy strategy at both the regional and national levels through its involvement in the European projects BIOMODEL4REGIONS and CEE2ACT. However, Greece lags behind other European countries in developing a bioeconomy strategy. Although many stakeholders are present, they lack the necessary information and appear hesitant or even resistant to participate in bioeconomy forums, workshops, and hubs. To address this issue, CluBE has assumed the role of engaging and informing relevant stakeholders at both the local and national levels.

The agricultural sector, particularly through the agri-food partnership, is poised to have a significant impact in Western Macedonia, a region undergoing transition [21,22]. To facilitate a seamless and equitable transition, training and capacity-building efforts in the broader agri-food sector are necessary [23]. Essential components include training for farmers, agricultural advice, production of educational materials, and creation of demonstration fields, as well as skill-building activities such as study visits and exchanges [24]. Dividing farmers into separate categories based on their varying perspectives, opinions, and worries could prove beneficial in devising tailored approaches for each group based on their unique characteristics. Cluster analysis can be used as a method to categorize farmers into exclusive groups [25,26].

The aim of this study was to investigate how farmers in the Western Macedonia region would like to be trained and informed in respect of the bioeconomy, based on their profiles, knowing the opportunities it offers, in order to develop a sustainable and acceptable training plan. For this purpose, a structured questionnaire specific to the case was created and presented to farmers in the WM region of Greece. The significance of the current study stems from the limited amount of attention that has been paid to training farmers about bioeconomy-related topics and the potential opportunities that come with the bioeconomy, either within Greece or internationally.

The structure of the study was designed to ensure a comprehensive understanding. Following this introduction, the study area and methodology are outlined in Section 2, the main results are presented in Section 3, Section 4 provides a discussion of the results and potential future avenues of research, and finally, Section 5 reflects on the main conclusions and limitations of the research.

2. Materials and Methods

2.1. Study Area

Western Macedonia, as shown in Figure 1, is the only region in Greece with borders that touch two Balkan countries and is the only region that does not have a coastal boundary [27]. The Western Macedonia region is partitioned into four distinctive regional units, namely Kozani, Grevena, Kastoria, and Florina, each possessing an exclusive economic profile with different industries playing a pivotal role in their respective economies (Figure 1). Over the past 60 years or more, Western Macedonia has displayed a combination of industrial and agricultural attributes due to the utilization of coal reserves for electricity production. This region contributes 2.2% to the national gross domestic product, mainly through the mining industry and agriculture. It is considered a "single activity" region, as it is the primary area for electricity production in the country [27].

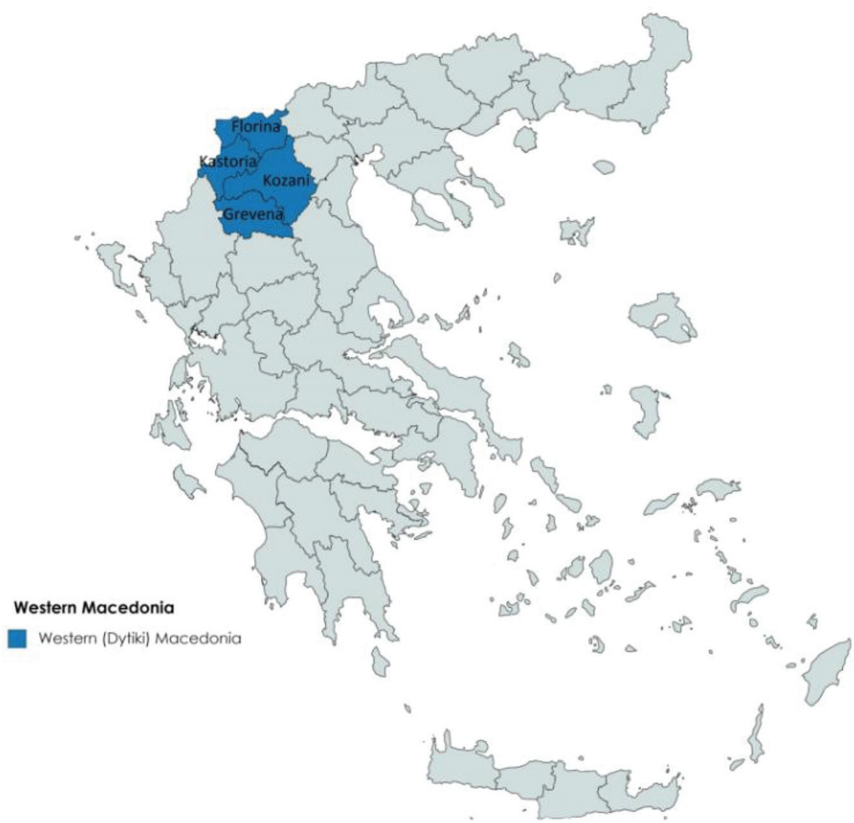

Figure 1. Map of Western Macedonia region.

Western Macedonia remains a hub for mining and energy production from lignite, having supplied energy to the nation for numerous decades [28–30]. However, the lignite sector has not generated significant industrial spillover effects that could have further catalyzed industrial growth and offset the losses from the decarbonization process. The region's specialization in other productive sectors remains weak to moderate, with a monoculture of lignite rendering the local economy highly dependent and vulnerable [31]. As a result, the entire region will be directly impacted by the decarbonization process.

Furthermore, the region has a significantly lower expenditure on research and development compared to the national average, according to an OECD study [32]. This indicates a limited capacity for the local research and production base to innovate, for the public sector to support innovation, and for the private sector to make structural adjustments to enhance competitiveness [33]. The decarbonization process is expected to result in the loss of approximately 10,600 jobs in Western Macedonia by 2029, both directly and indirectly, compared to the year 2019. It is also estimated that the region will experience a loss of more than EUR 1 billion in gross value added by 2029, or 26% of the region's GDP, compared to 2019 [34].

The decarbonization process will compound the already challenging socioeconomic situation in the region [35,36]. Western Macedonia is sparsely populated, with negative demographic indicators and an ageing population, as well as high unemployment rates, especially among women and young people, high rates of youth migration, and high poverty rates. Additionally, approximately 42,000 households and businesses in the region rely on district heating, with a total demand of approximately 600 GWh [31].

The majority of the 266,160 inhabitants of Western Macedonia reside in the regional units of Kozani and Florina, where 80% of the regional GDP is produced and the largest concentration of employment is located. According to the OECD [32], approximately 12,000 workers across the region are estimated to be affected by the decarbonization process, with the majority located in Kozani and Florina. The regional units of Kastoria and Grevena will mainly be affected due to indirect impacts on the lignite value chain and the reduction in employment and incomes in the entire region [33]. Thus, the decarbonization process will primarily impact the regional units of Kozani and Florina and secondarily the regional units of Kastoria and Grevena.

The agricultural sector in Western Macedonia, Greece, is a substantial contributor to the region's financial stability [37,38]. The region boasts fertile soil and an advantageous climate, which facilitates the growth of a diverse range of crops, including fruit, vegetables, and grains. The principal crops grown in Western Macedonia include apples, cherries, peaches, pears, tomatoes, peppers, cucumbers, wheat, barley, and corn. Additionally, the region is a noteworthy producer of livestock products, such as meat, milk, and cheese. A feature that distinguishes Western Macedonia from other regions in Greece in terms of farmers' behavior is the relative remoteness and isolation of some of its rural areas. This can impact the behavior of farmers in several ways. Farmers in remote areas may have limited access to markets, which can influence their decisions about which crops to grow and how to sell their products. They may be more likely to focus on crops that have a longer shelf life or are easier to transport. In addition, farmers in remote areas may be more self-sufficient, relying on their own resources and skills to produce food and other goods. This can influence their behavior in terms of how they manage their farms, what equipment they use, and how they market their products. The remoteness of some rural areas in Western Macedonia may also foster a stronger sense of community among farmers. They may be more likely to work together to share resources, such as labor and equipment, and to support each other in times of need.

In recent years, the agricultural sector in Western Macedonia has encountered difficulties due to the decrease in agricultural product prices, the rise in competition from imported goods, and the ramifications of global warming. However, the Greek government has implemented various programs and initiatives aimed at enhancing the competitiveness of local farmers and supporting the industry [39]. Despite these obstacles, the agricultural sector remains a crucial aspect of Western Macedonia's economy and provides employment opportunities for a considerable portion of the population. It is anticipated that the sector will continue to play a vital role in the economic progression of the region in the coming years.

2.2. Procedures and Measurements

The primary objective of this research was to explore farmers' perceptions of the opportunities arising from bioeconomy training. Agriculture is the key sector in which the bioeconomy can be implemented and have a positive impact, such as reducing environmental pollution and dependence on fossil fuels [11,40,41]. To achieve this objective, cluster analysis was employed as a method to categorize farmers based on their unique characteristics and perceptions (Figure 2).

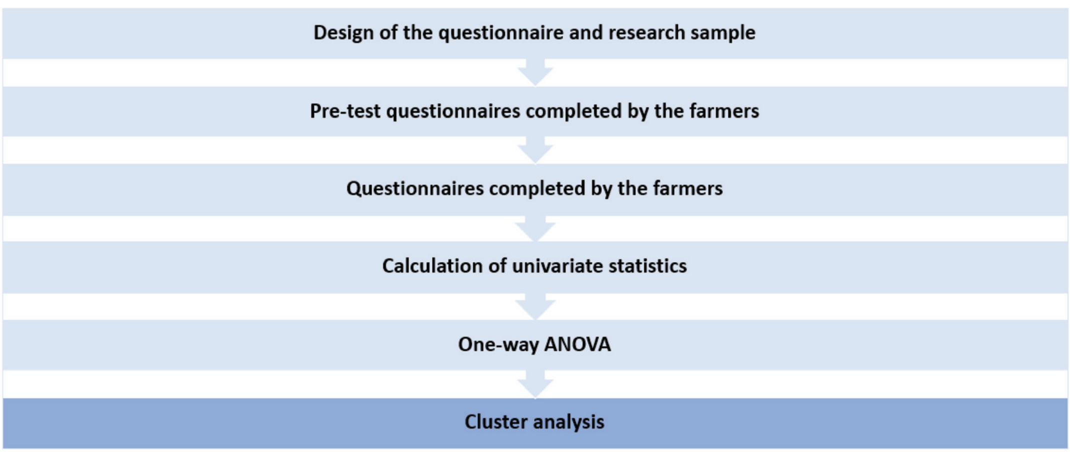

Figure 2. Methodology followed.

Cluster analysis is a technique used to group together statistical units or systems based on their similarities in observed variables, resulting in structures known as clusters [26,42]. The aim of this analysis is to divide the components into groups where the units within each group have high similarities to each other and are distinct from units in other groups [25]. This method effectively highlights relationships and patterns in the data that may not be easily recognizable through other means [43].

For this study, several statistical procedures were undertaken using the Statistical Package for Social Sciences (version 23). The research steps involved the following:

(1) Calculation of univariate statistics for all survey items before conducting any further statistical analysis.
(2) Usage of one-way ANOVA to determine differences between five sociodemographic variables in relation to the 22 items measuring the opportunities arising from the bioeconomy in the agricultural sector.
(3) A nonhierarchical cluster analysis, utilizing the k-means cluster algorithm, was performed on the 22 items measuring the perceived impacts.

This analysis did not take into account the sociodemographic variables, thereby enabling the classification of residents purely based on their perceptions and not their demographic characteristics.

The employment of cluster analysis in this study was validated by an earlier assessment, calculated using Kaiser–Meyer–Olkin statistics [44], yielding a score of 0.777 that surpassed the recommended threshold, and indicating the suitability of both the sample size and the number of variables.

With the stated objectives in mind, data collection was carried out through a questionnaire administered to farmers in all regional units of the Western Macedonia region between February and August 2022. The initial step in establishing the sampling frame was to identify the target population for the survey. A population refers to any comprehensive group of entities, such as individuals or organisms, that share a common set of characteristics that are crucial for the study's objectives. Researchers aim to make generalizable conclusions about this group [45]. The Hellenic Statistical Authority's Census of Agriculture and Livestock provides a numerical estimate of the population, indicating that in 2021, the number of farmers (including both owners and household members who are employed) in the Western Macedonia region was 24,205. A sample of 20 to 30 observations per group is enough to accurately detect subgrouping using k-means, with good precision both in determining the number of clusters in the sample and identifying the cluster membership of individual observations [46]. A total of 420 questionnaires were collected from farmers, with 412 deemed usable and included in the analysis.

Onsite sampling was conducted in the region to meet the needs of the survey, as opposed to online data collection [47]. This was because the physical presence of participants would ensure the accuracy and validity of their responses, thereby enhancing the quality of the results [48]. A researcher visited each community or household and asked potential farmers who were over 18 years old and willing to participate in the survey to share their perceptions about their familiarity with the concept of the bioeconomy. There were no instances of refusal to participate, although a protocol was in place to handle such situations.

A pretest [49] was conducted on 15 farmers between 15 and 20 January 2022. This exercise determined that filling in the questionnaire would take approximately 15 min, among other things. The final questionnaire contained two sections of questions. The first section contained questions on the demographic characteristics of farmers and the second section contained questions on attitudes and perceptions towards the bioeconomy.

Responses were evaluated using a Likert scale, where 1 represented an extremely unfavorable response (strongly disagree) and 5 indicated an extremely favorable response (strongly agree) [50].

3. Results

3.1. Respondents' Profiles and General Data

The survey sample's sociodemographic profile is mainly characterized by the following: 88.3% of the respondents were male, the most commonly represented age group was 46–55 years old (38.3%), 50.5% of respondents had a secondary education, and only 10.7% had a higher level of education. Additionally, the majority of respondents (33.3%) lived in the regional unit of Kozani, and 25.2% had an annual income of EUR 20,001 to 30,000. Detailed information on the respondents' profile can be found in Table 1.

Before delving into the results of the group analysis, it is important to provide some general information about the sample as a whole. By asking the question "Are you familiar with the concept of the bioeconomy" and using a Likert scale, we found that 57.52% of respondents were familiar with the concept and strongly agreed (56.80%) that information and training about the bioeconomy would bring benefits to farmers and their farms. When combining the respondents who agreed, we found that 75.97% held a positive view. Only 6.07% of respondents completely disagreed with this statement. This positive perception of the bioeconomy is not in line with previous findings by Stern et al. [51] and Wensing et al. [52]. However, this belief was found to be more prevalent when dealing with an emerging production model like the bioeconomy.

The belief that adopting bioeconomy practices would increase farmers' income is not widely held. Only 19.4% of farmers thought it would lead to an increase, while 28.9% thought it would lead to a decrease, and 51.7% had no answer. Thus, while farmers in the Western Macedonia region see the bioeconomy as an important opportunity, they are not confident it will benefit them personally. These results may reflect farmers' high expectations of the socioeconomic potential of the bioeconomy, or a lack of understanding of its implications. This is particularly relevant since the region has only one emerging opportunity through decarbonization. It is possible that this also indicates a lack of understanding about the implications of the bioeconomy, to some degree [53].

Table 1. Frequencies of sociodemographic profile of farmers.

Variable	Value	Frequency	Percentage
Sex	Male	364	88.3%
	Female	48	11.7%
Age	18–25	14	3.4%
	26–35	36	8.7%
	36–45	106	25.7%
	46–55	158	38.3%
	56–65	79	19.2%
	66+	19	4.6%
Education	Primary school	48	11.7%
	Secondary school	111	26.9%
	High school	208	50.5%
	University	44	10.7%
	Master's degree	1	0.2%
Regional unit of residence	Grevena	90	21.8%
	Kastoria	104	25.2%
	Kozani	137	33.3%
	Florina	81	19.7%
Annual household income	<EUR 10,000	37	9%
	EUR 10,001–20,000	97	23.5%
	EUR 20,001–30,000	104	25.2%
	EUR 30,001–40,000	64	15.5%
	>EUR 40,000	60	14.6%
	No answer	50	12.1%

Source: Authors' elaboration.

Table 2 displays the findings for the aforementioned questions and the reactions to the 22 declarations of potential opportunities emerging from the bioeconomy through farmer training. The Likert scale ranged from 1 (signifying "strongly disagree") to 5 (signifying "strongly agree") for all items. Upon scrutinizing the data, it is evident that, overall, the farmers surveyed were in concurrence with the affirmative outcomes of the bioeconomy and vehemently opposed certain inadequately financed training techniques.

The ANOVA analysis did not exhibit any statistically significant differences owing to the farmers' highly comparable responses. Nevertheless, the variables of age and education level were identified as the two primary discriminating factors that distinguished the perceived bioeconomic prospects. Specifically, age was determined to be a meaningful discriminator for sixteen of the items. The ANOVA findings outlined in Table 3 established that younger farmers demonstrated a greater inclination towards the potential benefits of bioeconomy training for farmers when compared to their older counterparts. These observations conform to prior investigations by Wensing et al. [52], Soubry et al. [54], and Donner et al. [55], which also indicated that older farmers are inclined to have a pessimistic viewpoint towards changes related to the implementation of a bioeconomic production model.

The level of education emerged as a noteworthy factor in distinguishing the perceived effects of the bioeconomy across fourteen different aspects. As per the findings in Table 4, farmers who possess higher levels of education exhibit greater faith in the opportunities that the bioeconomy can bring to the agricultural sector and demonstrate an interest in receiving local training. These outcomes align with previous research conducted by Petersen and Phuong [56], Tyndall et al. [57], and Poku et al. [58]. Moreover, a study by Case et al. [59]

found that farmers with advanced educational qualifications were more likely to agree on the potential benefits of the bioeconomy in the agricultural sector.

Table 2. Total responses to 2 general questions and 22 questions on opportunities and training in respect of the bioeconomy.

		Likert Scale						
		1	**2**	**3**	**4**	**5**	**M**	**SD**
General questions	Are you familiar with the concept of the bioeconomy?	6.07	2.67	15.29	18.45	57.52	4.19	1.162
	Bioeconomy information and training benefits farmers and their holdings	5.34	2.43	15.05	20.39	56.80	4.14	1.138
Opportunities	Environmental protection	1.46	2.18	5.10	25.97	65.29	4.51	0.812
	Sufficient biomass quantity	1.21	4.37	8.74	22.82	62.86	4.42	0.910
	Existence of policy	3.16	5.34	9.47	26.21	55.83	4.26	1.041
	Technology development	1.70	6.80	12.38	50.49	28.64	3.98	0.915
	Waste reduction	1.21	5.83	19.66	28.88	44.42	4.09	0.988
	Saving water resources	0.73	7.52	11.89	42.96	36.89	4.08	0.922
	Production increase	22.82	7.52	13.83	16.99	38.83	3.42	1.595
	Energy production	17.48	9.47	15.05	20.39	37.62	3.51	1.499
	Improving health	2.18	17.48	14.08	28.16	38.11	3.83	1.179
	Increasing consumption	17.96	6.55	18.69	18.45	38.35	3.53	1.493
	Food and feed production	2.43	5.34	16.50	31.80	43.93	4.09	1.015
	Land use change	2.43	13.35	14.56	19.90	49.76	4.01	1.183
	Financial resources for investments	1.70	5.34	12.38	24.51	56.07	4.28	0.988
	Research and innovation for new products and processes	2.18	11.65	9.47	20.87	55.83	4.17	1.136
	Exploiting renewable resources	4.61	10.19	22.57	25.49	37.14	3.80	1.177
	Climate change mitigation	1.46	10.92	23.06	27.43	37.14	3.88	1.076
	Pollution reduction	3.64	10.19	7.52	35.92	42.72	4.04	1.113
Training	Training programs at local level	58.50	8.50	4.61	9.71	18.69	2.22	1.631
	Training programs at local level (subsidized)	13.83	3.88	6.31	10.44	65.53	4.10	1.454
	Training in a regional center (subsidized)	46.36	9.47	8.98	9.71	25.49	2.58	1.703
	Information in the form of leaflets	86.89	2.91	2.91	3.64	3.64	1.34	0.970
	Theoretical online courses	82.52	4.37	4.85	2.67	5.58	1.44	1.085

Source: Author's elaboration.

Table 3. Mean scores and ANOVA tests by age.

Impact of Bioeconomy in Agriculture	**18–25 (n = 14)**	**26–35 (n = 36)**	**36–45 (n = 106)**	**46–55 (n = 158)**	**56–65 (n = 79)**	**+66 (n = 19)**	**F**	***p*-Value**
Environmental protection	4.43	4.06	4.54	4.59	4.61	4.32	3.127	0.009
Sufficient biomass quantity	4.86	3.89	4.58	4.45	4.48	3.63	7.269	0.000
Existence of policy	4.71	3.75	4.32	4.35	4.38	3.37	5.882	0.000
Technology development	3.86	4.17	3.78	4.02	4.16	3.63	2.636	0.023
Production increase	4.26	3.28	3.27	3.25	3.87	3.26	2.777	0.018
Energy production	4.29	3.61	3.38	3.28	3.99	3.42	3.374	0.005
Improving health	4.50	3.92	4.05	3.55	3.90	3.89	3.611	0.003
Increasing consumption	3.79	3.56	3.90	3.20	3.75	3.00	3.816	0.002
Food and feed production	4.36	3.69	4.17	4.08	4.27	3.63	2.725	0.020
Research and innovation for new products and processes	4.43	3.78	3.75	4.32	4.47	4.42	6.025	0.000
Exploiting renewable resources	4.14	3.69	3.60	3.93	3.65	4.47	2.853	0.015
Climate change mitigation	4.57	3.72	3.55	4.04	3.90	4.11	4.362	0.001
Pollution reduction	4.64	3.72	3.56	4.26	4.25	4.16	7.861	0.000
Training programs at local level	3.00	3.36	1.92	2.25	2.05	1.53	6.078	0.000
Training in a regional center (subsidized)	2.93	4.00	2.54	2.39	2.43	2.21	6.217	0.000
Theoretical online courses	1.00	2.56	1.41	1.35	1.33	1.11	9.757	0.000

Source: Author's elaboration.

Table 4. Mean scores and ANOVA tests for education level.

Impact of Bioeconomy in Agriculture	Primary School (n = 48)	Secondary School (n = 111)	High School (n = 208)	University (n = 44)	Master's Degree (n = 1)	F	*p*-Value
Environmental protection	4.33	4.70	4.44	4.66	2.00	5.538	0.000
Sufficient biomass quantity	4.06	4.56	4.42	4.48	2.00	4.454	0.002
Existence of policy	3.98	4.42	4.31	3.98	2.00	3.776	0.005
Technology development	4.15	3.85	3.97	4.18	2.00	2.738	0.028
Saving water resources	4.04	3.95	4.11	4.32	2.00	2.634	0.034
Production increase	4.40	2.86	3.40	3.84	2.00	9.683	0.000
Energy production	4.29	2.91	3.55	4.00	3.00	9.724	0.000
Improving health	4.21	3.62	3.78	4.14	3.00	3.110	0.015
Food and feed production	3.81	4.33	4.11	3.80	2.00	4.649	0.001
Exploiting renewable resources	4.23	3.60	3.75	4.11	3.00	3.439	0.009
Training programs at local level	2.40	1.62	2.25	3.32	3.00	9.694	0.000
Training in a regional center (subsidized)	3.67	1.90	2.57	3.25	1.00	12.470	0.000
Information in the form of leaflets	1.56	1.13	1.31	1.82	1.00	4.922	0.001
Theoretical online courses	1.31	1.24	1.37	2.48	1.00	12.723	0.000

Source: Author's elaboration.

Few significant differences were found in relation to the perceived opportunities among the remaining three independent variables, namely, sex, regional unit of residence, and income.

3.2. Cluster Analysis

Consistent with prior research [60–64], a nonhierarchical k-means cluster analysis was employed. This particular method is specifically designed to classify cases rather than variables and is more efficient for analyzing larger datasets (n > 200) compared to the hierarchical technique [65]. However, it does require a predetermined specification of the number of groups to be formed.

Adopting the approach employed by Violán et al. [60] and Murray and Grubesic [61], a stepwise methodology was utilized to construct 2–5 groups, founded upon the mean score of 22 items measuring the opportunities arising from farmers' bioeconomy training. Table 5 presents the distribution of the sample percentages among each group and among the various groupings (ranging from two to five groups). As evidenced by the data, the selection of four or five groups yields a minority grouping that accounts for less than 10% of the overall sample. For simplicity and ease of understanding the results, it was decided to limit the clusters to three.

Table 5. Percentage of sample within each group.

	Number of Groups			
Clusters	**2**	**3**	**4**	**5**
1	81%	56%	22%	21%
2	19%	21%	44%	9%
3	-	23%	25%	22%
4	-	-	9%	32%
5	-	-	-	17%

Source: Author's elaboration.

Having completed the nonhierarchical k-means cluster analysis, an alternative cluster approach was employed to test the robustness of the clustering results. In particular, a two-step cluster analysis (TSCA) was additionally employed automatically selecting the number of clusters and including the same predictors as in the nonhierarchical k-means cluster analysis. The selection of the TSCA was based on the qualitative nature of the variables of the research instrument [37,66,67]. TSCA suggests an optimal solution of four clusters very similar to the nonhierarchical k-means cluster analysis, both in size and characteristics. In particular the first cluster includes 22% of the sample members, the second cluster includes 7.5% of the sample members, the third cluster includes 21.5% of the sample members, the fourth cluster includes the 34% of the sample members while 15% of the sample members is not categorized in any cluster although they behave like its fifth cluster of the nonhierarchical k-means analysis. TSCA results verify the robustness of the employed nonhierarchical k-means cluster analysis and thus initial clustering was accepted and included in the multivariate statistical methodology that follows.

The examination of the various clusters involved an analysis of the mean values for 22 elements related to opportunities arising from the bioeconomy (Table 5), which helped to determine the degree of agreement or disagreement among farmers regarding these elements for each cluster. Table 6 also indicates that all impacts made a significant contribution in identifying the clusters (*p*-value = 0.000). Among the impacts that differentiated the clusters the most were "training programs at local level", "Training in a regional center (subsidized)", "information in the form of leaflets", and "theoretical online courses". They all represent the kind of training with which farmers would like to be updated. The issue of "training programs at local level (subsidized)" appears to be a point of agreement for farmer consensus and has been previously observed by other researchers such as Lokhorst et al. [68]. Looking at perceived opportunities, the item that demonstrates a lesser degree of differentiation between clusters is "sufficient biomass quantity".

Table 6. Perceptions about opportunities and training in respect of the bioeconomy among clusters (percentage agreeing [a] and average scores [b]).

	Cluster 1, n = 229 (56%)		Cluster 2, n = 87 (21%)		Cluster 3, n = 96 (23%)			
	Agree (%)	Average Scores	Agree (%)	Average Scores	Agree (%)	Average Scores	F-Ratio	*p*-Value
Opportunities								
Environmental protection	90.4	4.54	57.5	3.51	100.0	4.96	72.581	0.000
Sufficient biomass quantity	96.5	4.62	67.8	3.76	100.0	4.96	89.645	0.000
Existence of policy	86.9	4.35	49.4	3.32	100.0	4.91	74.058	0.000
Technology development	91.7	4.36	47.1	3.09	78.1	3.86	87.023	0.000
Waste reduction	74.2	4.21	41.4	3.09	100.0	4.72	95.909	0.000
Saving water resources	90.8	4.33	33.3	3.02	95.8	4.44	111.742	0.000
Production increase	94.8	4.63	13.8	2.75	1.0	1.13	1081.135	0.000
Energy production	94.8	4.62	25.3	2.93	0.0	1.40	829.742	0.000
Improving health	96.9	4.50	21.8	2.83	33.3	3.13	145.195	0.000
Increasing consumption	89.5	4.46	9.2	2.68	21.9	2.06	214.374	0.000
Food and feed production	86.0	4.30	24.1	2.95	97.9	4.64	113.449	0.000
Land use change	74.7	4.12	42.5	3.09	82.3	4.58	47.173	0.000
Financial resources for investments	90.8	4.48	32.2	3.03	100.0	4.94	175.691	0.000
Research and innovation for new products and processes	92.6	4.59	33,3	2,93	78.1	4.28	99.901	0.000
Exploiting renewable resources	72.1	3.94	24,1	2,95	75.0	4.24	36.161	0.000
Climate change mitigation	78.6	4.19	31,0	2,98	61.5	3.95	50.126	0.000
Pollution reduction	93.4	4.42	42.5	3.00	76.0	4.07	68.016	0.000
Training								
Training programs at local level	37.1	2.54	34.5	2.45	2.1	1.23	25.779	0.000
Training programs at local level (subsidized)	79.5	4.22	46.0	2.98	94.8	4.82	47.339	0.000
Training in a regional center (subsidized)	38.4	2.77	58.6	3.45	6.3	1.35	45.862	0.000
Information in the form of leaflets	7.4	1.36	14.9	1.68	0.0	1.00	11.812	0.000
Theoretical online courses	8.7	1.50	13.8	1.69	2.1	1.08	8.138	0.000

Source: Author's elaboration. [a] Percentage agreeing are those answering four or five on the five-point scale. [b] Scale ranges from 1 = completely disagree to 5 = completely agree.

Table 7 presents the results obtained from the cluster analysis, in terms of the demographic and social profile of farmers belonging to the three groups.

Table 7. Demographic profile of the three clusters of farmers.

	Cluster 1		Cluster 2		Cluster 3		Chi-Squared Value	*p*-Value
	N = 229	**56%**	**N = 87**	**21%**	**N = 96**	**23%**		
Sex							10.489	0.05
Male	202	88.2%	70	80.5%	96	95.8%		
Female	27	11.8%	17	19.5%	4	4.2%		
Age							18.345	0.049
18–25	11	4.8%	3	3.4%	0	0.0%		
26–35	17	7.4%	13	14.9%	6	6.3%		
36–45	55	24.0%	20	23.0%	31	32.3%		
46–55	82	35.8%	34	39.1%	42	43.8%		
56–65	54	23.6%	12	13.8%	13	13.5%		
66+	10	4.4%	5	5.7%	4	4.2%		
Education							32.944	0.000
Primary school	36	15.7%	12	13.8%	0	0.0%		
Secondary school	48	21.0%	22	25.3%	41	42.7%		
High school	117	51.1%	42	48.3%	49	51.0%		
University	28	12.2%	10	11.5%	6	6.3%		
Master's degree	0	0.0%	1	1.1%	0	0.0%		
Regional unit of residence							185.821	0.000
Grevena	20	8.7%	5	5.7%	65	67.7%		
Kastoria	82	35.8%	16	18.4%	6	6.3%		
Kozani	81	35.4%	31	35.6%	25	26.0%		
Florina	46	20.1%	35	40.2%	0	0.0%		
Income							160.167	0.000
<EUR 10,000	26	11.4%	11	12.6%	0	0.0%		
EUR 10,001–20,000	68	29.7%	23	26.4%	6	6.3%		
EUR 20,001–30,000	75	32.8%	26	29.9%	3	3.1%		
EUR 30,001–40,000	16	7.0%	11	12.6%	37	38.5%		
>EUR 40,000	13	5.7%	7	8.0%	40	41.7%		
No answer	31	13.5%	9	10.3%	10	10.4%		

Source: Author's elaboration.

4. Discussion

According to the findings obtained, the three clusters that were retained can be characterized as the engaged, the restricted, and the partially engaged [69].

Cluster 1—The engaged: They represent the largest group, comprising 56% of the sample. This group exhibits a strong inclination towards bioeconomy opportunities that are aligned with sustainable production and consumption, environmental awareness, and areas that do not have a direct impact on their farms, such as "waste reduction" and "land use change". Over 90% of them acknowledge the potential of the bioeconomy to offer "sufficient biomass quantity", "improving health", "energy production", "pollution reduction", and "technology development".

When compared to the other clusters, the engaged group shows a higher conviction towards the potential of the bioeconomy, with 92.6% agreeing that it contributes to research and innovation for new products and processes, 89.5% seeing it as a means to increase consumption, and 94.8% recognizing its potential for energy production.

However, none of the statements managed to achieve high levels of agreement within the group. In terms of demographics, this group primarily consists of middle-aged men with a high-school education, slightly more so than the other groups. (Table 7 shows the demographic profile).

Cluster 2—The restricted: This group constitutes the smallest percentage (21%) of the farmer sample and is characterized by strong convictions with no expectation of benefits from adopting a bioeconomic production model. They appear largely unconcerned with issues related to production, consumption, and health, but exhibit consensus around the importance of "sufficient biomass quantity" and "environmental protection". Unlike the first cluster, this group is skeptical about the potential benefits of technological development, climate change mitigation, and pollution reduction that the bioeconomy can offer.

This cluster is the most balanced in terms of regional unity and age, primarily consisting of residents of the regional unit of Florina aged between 46 and 55 years old, with incomes ranging from EUR 20,001 to EUR 30,000. Despite their reluctance to embrace the bioeconomy, they express a willingness to participate in subsidized regional programs that offer training in bioeconomic topics. According to the views of the locals, they can accept changes with financial incentives.

Cluster 3—The partially engaged: The second largest group surveyed, comprising 23% of the farmers, holds the most favorable perceptions towards "environmental protection", "sufficient biomass quantity", "existence of policy", "waste reduction", and "financial resources for investments". These opportunities are associated with sustainable and optimal utilization of natural and financial resources. As in cluster 1, the partially engaged farmers show a keen interest in conserving water resources and producing food and feed, and they also prefer to learn about the bioeconomy through subsidized local programs.

Interestingly, in this group, none of the respondents viewed energy production as a bioeconomy opportunity. This could be attributed to the fact that 67.7% of these farmers live in the regional unit of Grevena, which has never had an economy based on energy production, unlike Kozani and Florina. Although there are no investments in renewable energy sources due to the mountainous terrain and lack of plains, the agricultural sector, especially livestock farming, is well developed. This is evident from Table 7, where 41.7% of the farmers in this group reported an annual income of more than EUR 40,000, which is remarkably high, particularly for Western Macedonia and Greece as a whole.

It can be noted that the bioeconomy is a rapidly growing sector with great potential for farmers to increase their productivity and income [5,70–73]. The bioeconomy refers to the sustainable use of renewable biological resources to produce food, feed, bio-based products, and bioenergy [3,74–77]. The bioeconomy not only has economic benefits, but also contributes to environmental sustainability and rural development [24,78–80].

To initiate the training of farmers in respect of the bioeconomy, the foremost task is to impart to them a comprehensive view of the bioeconomy concept and its essentiality. The bioeconomy does not solely focus on augmenting yield, but also emphasizes producing better and more sustainable products [81]. Farmers must acknowledge that the bioeconomy involves utilizing renewable biological resources in a sustainable way to meet human needs and enhance their welfare [82]. Moreover, they should comprehend the advantages of the bioeconomy for their own operations, including amplified productivity and income, decreased dependency on fossil fuels, improved soil and water quality, and lowered greenhouse gas emissions [83]. Additionally, the bioeconomy presents novel opportunities for farmers to broaden their operations and venture into new markets [4].

This study was an initial approach to explore the perceptions of West Macedonian farmers about the opportunities arising from their training and awareness in respect of bioeconomy issues. Future research can be carried out in various areas that can enhance the training of farmers on the bioeconomy and better farming practices. With the increasing availability of digital technology in rural areas, there is an opportunity to create training programs that incorporate technology-based solutions such as mobile applications, e-learning platforms, and virtual reality simulations. Further research can investigate the effectiveness of these methods in improving farmers' learning and adoption of new practices.

Participatory learning approaches that involve farmers in the learning process, encouraging them to share their experiences and knowledge, and facilitating peer learning can also be effective. Research could be conducted to explore the effectiveness of these approaches in promoting the adoption of new practices by farmers and building community knowledge and resilience. In fact, research has shown that farmers are willing to participate in mainly local programs.

Sex inequalities can also limit women's access to resources and opportunities in agriculture. Thus, further research could focus on designing and implementing sex-sensitive training programs that empower female farmers to take leadership roles and improve their productivity.

In addition, climate change is a major challenge to agriculture, leading to changing weather patterns and increased frequency of extreme weather events. Research can explore how to train farmers in climate-smart farming practices such as conservation agriculture, agroforestry, and climate-resilient crop varieties.

Finally, developing bioeconomy value chains requires improving the linkages between farmers, input suppliers, processors, and markets. Hence, research could be conducted to explore how to train farmers to deal more effectively with these factors and to identify and exploit market opportunities.

5. Conclusions

Despite numerous empirical studies conducted at the international level regarding farmers' attitudes towards the bioeconomy and the potential opportunities it presents, Greek researchers have paid little attention to this issue. Moreover, none of the existing research has examined the differentiation of farmers' perceptions. The principal driving force behind this study was to fill this gap. Additionally, agricultural subsidies are currently contingent upon the implementation of the bioeconomy and associated practices, including renewable energy production. Furthermore, agriculture will play a significant role in the study region's transition, since it is the second largest productive sector following energy.

There are several reasons why it is crucial to train farmers. Firstly, the agricultural sector is dynamic, with the introduction of new technologies and practices necessitating that farmers keep up to date with the latest developments to leverage their benefits. Secondly, numerous farmers lack fundamental knowledge about agricultural practices, including soil fertility management, crop protection, and utilization of contemporary inputs, leading to low productivity and reduced income. Thirdly, many farmers confront obstacles such as limited water resources, rising energy prices, and fluctuating climatic conditions, necessitating a comprehensive grasp of modern management practices stemming from the bioeconomy.

Incorporating cluster analysis can provide a targeted strategy for organizing bioeconomy training and awareness initiatives by dividing farmers into distinct groups based on their shared perspectives of bioeconomy prospects. The research findings indicate that, despite varying opinions on the benefits of bioeconomy opportunities, farmers in the Western Macedonia region exhibit substantial support for subsidized bioeconomy training. Given the nascent status of the bioeconomy, it is reasonable to expect farmers to hold diverse views on the advantages it could offer.

The present study is subject to certain limitations, including its narrow focus on farmers from Western Macedonia. While the survey's inclusion criteria were clearly defined, the researchers' potential bias in selecting farmers cannot be completely ruled out. Additionally, the study presupposes that the government will adopt a training strategy to boost the bioeconomy and involve farmers as key participants in this initiative. Given that farmers represent a vital component of the bioeconomy, their inclusion in such a strategy is anticipated.

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Article

Mobilizing the Midstream for Supporting Smallholder Intensification

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Abstract: Most policies and incentives that aim to enable smallholder farmers towards the intensification of their agri-food production systems focus on supply-side strategies, such as training, technical assistance or credit services. Far less attention is usually given to demand-side drivers, such as the role of midstream value chain actors supporting smallholder's investments in primary production. This explorative paper provides new insights on the value addition in the production vs. the midstream segments of agri-food value chains. It focusses attention on the influence of value chain integration on smallholders' production and investment opportunities, and the implications for the structure of primary production. We use data from several value chains in sub-Saharan Africa to illustrate how farmers link to commercial midstream actors are able to enhance resource productivity, efficiency and profitability. In addition, we show that a larger role of the midstream in value added creation is associated with a more equal farm size distribution.

Keywords: smallholders; agri-food value chains; agricultural intensification; midstream value added; farm-size distribution

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1. Introduction

Intensification of smallholder agricultural production is generally considered a key strategy for supporting their competitive position in agri-food systems [1]. Changes in cropping patterns, improvements of land use practices and investments in yield-enhancing inputs can provide positive returns to smallholders and, by resulting in large volumes, can improve their bargaining power vis-à-vis midstream actors, such as rural traders and processors. Large volumes allow farmers to spread-out the costs of accessing alternative markets and thus increases their outside options in bargaining with buyers. This is, however, not a zero sum game but may, in fact, lead to scale-economies and quality improvements that further reduce transaction costs and increase the value added potential for midstream actors too [2]. Therefore, smallholder intensification in primary production can be supported by value added upgrading in the mid-stream segment of value chains and these can thus become mutually reinforcing processes. Technology adoption in agriculture has, however, remained strikingly low in many sub-Sahara Africa countries and therefore production systems are rather stagnant [3]. Even while agricultural production in Africa slightly increased over the past decades, such progress is mainly attributed to land area expansion and mobilization of agricultural labour force and far less to increased use of yield-enhancing technologies [4].

Most explanations in the literature relate to supply-side constraints, such as inadequate access by farmers to finance and high-quality farm inputs [5–9]. Far less attention is given to the role of mid-stream value chain actors. This group includes a wide array of rural collectors, traders, truck drivers, shipping agents, warehouses, moneylenders and banks, and standard control agents. These mid-stream agents interact with farmers through spot exchange [10,11] but also through contractual exchange systems where farmers receive input support (seeds, fertilizers, equipment) and engage in delivery arrangements against pre-arranged prices [12].

High risks, uncertainties, and the inability to meet quality standards in primary production result in supply shortages for midstream agribusinesses involved in bulking, storage, processing and trade. Since consumer food demand continues to increase due to high growth in population and consumer income, the use of sustainable modern technologies for raising agricultural productivity become indispensable, also for these mid-stream actors.

Mid-stream agents can affect smallholder intensification through a number of channels [13]. The first is by providing farmers access to (higher value) markets as higher productivity (in terms of higher yields or higher revenue per hectare) can result from incentives to invest related to quality standards set by mid-stream agents. Second, prices paid by the mid-stream segment impact agricultural productivity directly (in terms of revenue per hectare or per hour worked) and indirectly, by providing an incentive to adopt yield-enhancing technologies. As a second-order effect, enhanced farm revenue may, in turn, provide farmers with increased access to finance to make productivity-enhancing investments. A final channel is through institutional innovations within the value chain introduced by lead firms that can enhance farms' access to productivity-enhancing technology.

The empirical literature studying this predominantly looks at the farm-level effects of participating in certain *types* of value chains, such as value chains for urban supermarket chains [14] and export agencies or value chains governed by contractual relationships [15] and other forms of value chain governance [16]. This literature uses farm-level micro-data to better understand the effect of the mid-stream and downstream parts of the value chain on farm-level income, productivity, and wellbeing.

Most pathways towards agricultural intensification focus on incentives for improving farmers' access to knowledge and resources [17] and look at the effectiveness of the delivery mechanisms towards smallholder farmers. A comprehensive overview of different types of incentives shows that risks and credit constraints mostly limit technology adoption in developing countries [18]. Few studies have analysed incentives implemented through value chains integration and the role of inclusive value-chain development [16,19]. Linkages between producers and midstream actors are helpful to reduce risks and uncertainties regarding sales volume, quality and prices. Overcoming these constraints is increasingly important as a driver for adoption of improved production practices and technologies.

This article offers a new meso-level analytical framework for studying the linkages between the midstream value chain and the primary agri-food production sector. It draws on comparative data from six different agri-food value chains in sub-Saharan Africa (SSA) to study the structural relationship between smallholder farmers production and value addition in the midstream segment. The amount of value addition taking place in the midstream is an indication for its strength, either in terms of its ability to add value or the capacity to bargain for a larger surplus vis-à-vis farmers and retailers. The analysis relies on a detailed reconstruction of the cost and revenue structure along different stages of the value chain that is subsequently used to assess sector-wide effects on factor intensity and farm-size structure at primary production.

Our analysis aims to better understand the role and importance of midstream agents in the value added generation throughout the agricultural supply chain, its impact on smallholder's resource use and investment decisions and the implications thereof for farm size competitiveness in the supply chain (see Figure 1). We show how strength in the midstream trade and processing activities is closely related to farm-level changes in capital and labour use, and influences the farm size structure for commercially-oriented smallholder production.

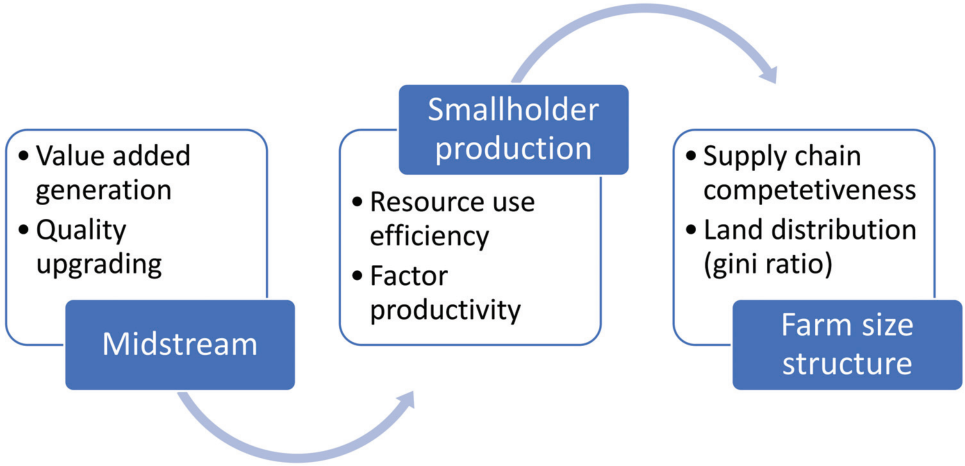


Figure 1. Linkages between midstream, smallholder production and farm structure.

The remainder of this article is structured as follows. Section 2 outlines the analytical framework for assessing interactions between primary production and midstream value chain operations. Section 3 presents the data and discusses the methods for comparative data analysis. In Section 3 the empirical results are presented, followed in Section 4 by a discussion on the policy implications and the prospects for further research on the role of production-midstream linkages for agricultural and rural development.

2. Materials and Methods

This study relies on empirical field data generated by the Value Chains Analysis for Development (VCA4D) project, funded by the European Union/DEVCO and executed through the Agrinatura network. It uses a data collection and analysis approach that carefully separates between value added generation in primary production and in midstream activities. Therefore, a functional analysis is made of the product flows and transformation processes throughout the value chain and of the actors involved in these activities. Hereafter, the economic performance of each of the actors involved in the value chain activities is reconstructed, using field survey data from a selected sample of each of the actors. In addition, social conditions and environmental effects (using a life cycle approach) are assessed with interviews and case studies. This paper relies only on the value added data from the economic analysis.

The purpose of VCA4D program is to provide evidence-based information for assessing inclusive and sustainable agricultural development strategies. The analysis is directed to policymakers and business stakeholders to support a constructive policy dialogue on the opportunities and constraints for value chain upgrading. Comparing different agricultural VCs is considered helpful to uncover major development pathways, and to identify at which stages of the value chain and for which actors opportunities for investment and technical support can generate tangible economic benefits, and how specific strategies can be designed to foster VC sustainability and inclusiveness.

2.1. Value Added Composition

The VCA4D program analyses agricultural value chains according to the sequence of production processes from the primary production to its end uses. It considers a sequence of different types of actors involved in the production and exchange of commodities orientated towards the final market. Major actors are input providers (for seed and fertilizers), farmers, traders and collectors, transporters, processors, wholesalers (including storage) and retailers. In addition, there are several public and private agencies involved to control on quality and safety standards, collecting taxes and to maintain lawful exchange relationships.

The VCA4D program uses a stylized methodological framework to assess the structure and performance of VCs from an economic, social and environmental perspective. This includes a functional analysis that identifies the different stakeholders involved in agricultural VC, followed by a technical diagnosis of the activities performed at different stages and an analysis of the underlying governance and power structures. Finally, the composition of the production value and the value added created at different stages of the VC is reconstructed to enable a further assessment of resource use intensity, labour productivity, capital intensity and profitability.

Figure 2 illustrates how the value that is realized in primary production and subsequently in midstream operations is decomposed into the costs of purchased intermediary inputs (such as seeds and fertilizers in agricultural production, and the raw materials purchased as inputs for the food industry) and a number of additional inputs, ranging from land (rent), labour (wages), finance (interest paid for credit), depreciation (degradation of the stock of capital resources) and taxes, subsidies and fees (paid to/by the government) to generate a gross market value. What remains after compensating for the costs of these inputs is an operating profit that compensates for the business initiative and covers the entrepreneurial risk.

Figure 2. Composition of value added.

The decomposition of the value added by stages of the value chain (between primary production and midstream activities) permits to identify the stage of development and the degree of vertical integration of agri-food production. Moreover, the shares of intermediary inputs, labour costs and capital depreciation compared to total value added offer insight into the relative factor intensity of production and midstream activities. Finally, the comparison between operational profit with total value added creation illustrates the profitability of activities.

The decomposition of the value added permits the calculation of several performance indicators. The proportional shares of value added creation and employment generation are divided between primary production and midstream activities. Capital intensity is defined as the ratio between depreciation costs and total value added, whereas input intensity is the ratio between intermediary inputs and total value added. Profitability refers to the operating profit as a share of value added. These intensity indicators are calculated separately for primary production and midstream activities. The Gini ratio of primary production reflects the cumulative proportion of the population of farmers against the cumulative proportion of the value added that they generate. It ranges between 0 in the case of perfect equality and 1 in the case of perfect inequality.

2.2. Value Chain Configurations

We selected from the VCA4D portfolio six studies that cover different categories of production systems and value chains, focussing on cases from the sub-Sahara region in order to control for major variation from contextual sources. This explorative analysis of primary production and midstream operations is useful for developing some hypothesis about the potential effects of value added distribution on the factor intensity of production systems and the composition of the firm structure. This enables a comparison of the importance of some 'typical' midstream value chain configurations for different categories of products (see Table 1):

- Commodities: cotton in Ethiopia [20] and cocoa in Cameroon [21]
- Commercial crops: green beans in Kenya [22] and sorghum in Ghana [23]
- Staple Foods: maize in Nigeria [24] and groundnut in Ghana [25]

Table 1. Primary production and value chain characteristics.

Commodity	Country	Farm Type	Production Systems	Marketing Systems	Labour Use
Cotton	Ethiopia	Small, medium and large farms	Rainfed/conventional	Cooperatives and Contracts	Family labour and temporary contract labour
Cocoa	Cameroon	Small-scale producers	Input intensive	Producers groups and regional confederations	Family labour
Green beans	Kenya	Small-scale (with self-help groups)	Greenhouse	Contract farming for exports	Family and hired labour (permanent)
Sorghum	Ghana	Small-scale commercial farmers	Semi-technified; input-credit by large aggregators	Customary deliveries to aggregators and processors	Family labour and seasonal hired labour
Maize	Nigeria	Commercial smallholders	External-input technology	Contracts with aggregators (regional sales to urban centres and for livestock feed)	Family labour complemented by wage labour
Groundnut	Ghana	Small-scale producers	Labour-intensive production	Input-output contracts	Family and hired labour (planting and harvesting)

Table 1 provides an overview of the production conditions and the commercial regimes for each of these crop/market combinations. They show clear differences in farm organization (small-scale to family farmers) and production technologies (traditional to semi-technified) accompanied by a diversity in labour arrangements (family, hired, contract) and a large variation in market outlets (custom, contract, auction).

Classical commodities cotton and cocoa are produced by a large number smallholders in countries under fairly strict control by the government (Ethiopia) or by multinational firms (Cameroon). Commercial crops like green beans (Kenya) and sorghum (Ghana) are procured by processing firms and sold on global and local markets. Traditional staple foods such as maize (Nigeria) and groundnut (Ghana) involve many low-input smallholders that deliver to their produce to artisanal processors for local and regional sales.

2.3. Brief Characterization of Selected Value Chains

Cotton in Ethiopia: production is divided between 7000 traditional and 19,000 semi-modernized family farms, and a few very large commercial farms that use irrigation and modern inputs and control 2/3 of the land and value added. The traditional cotton sector generates 60,000 self-employed jobs, whereas in the modern sector 40,000 jobs are created. Local spinning and traditional weaving are gradually replaced by industrial ginneries and spinning mills, as well as several medium- and large size oil processing mills. The development of cotton is promoted by government to substitute imports and eventually to promote exports, but high production costs and low value chain efficiency remain important constraints.

Cocoa in Cameroon: mixed production structure dominated by 200,000 smallholders producing 70% of output that is sold at local spot-markets alongside 90,000 family farmers producing the remainder under contract conditions. Production involves some 100,000 seasonal workers. Aggregation is divided between 1500 local intermediaries and organized cooperatives that control 40% of production, of which 1/3 is certified. There are 3 local processing plants that buy 22% of production (processed into butter and paste) and 6 large multinationals that control major share of exports. Main profits are realized by export traders, while cocoa value chain also remains important for fiscal levies.

Green beans in Kenya: involves primary production by some 20,000 scattered smallholders delivering on spot markets and 32,000 mid-size family farmers delivering green beans on contract, alongside some 60 large farms that control 45% of market deliveries. This bimodal production structure is linked to a marketing structure where a few packhouses and canning factories control 90% of all processing and sales. Half of the production is exported as fresh or canned beans, whereas 40% is rejected and remains for domestic consumption and 10% is lost and used for animal feed and compost.

Sorghum in Ghana: some 175,000 low-input smallholders and 47,000 more technically advanced smallholders are responsible for 98% of all sorghum production. One-third of output is locally consumed and post-harvest losses are 12%. From the marketed surplus, 80% is used by local micro-brewers and 15% by industrial brewers. This smallholder-dominated production structure is linked to a rather decentralized midstream trader and processor organization with low entry costs and very lucrative margins.

Groundnut in Ghana: primary production is dominated by 375,000 family farmers that produce about 90% of output, complemented by some 28,500 small- and midsize producers that deliver the remainder under contracts with buyers. Market orientation is diversified, including informal and formal aggregators and a whole range of different processors (i.e., paste, flour, *kulikuli*, snacks). The groundnut value chain offers employment to some 440,000 self-employed and 350,000 wage workers, but wages are far below living income standards. Women play a key role in production, trade and processing. The informal value chain with a large number of SMEs accounts for 88% of all processing activities.

Maize in Nigeria: half of the maize is produced by more than 2.5 million local smallholders and the other half is divided between some 350,000 more commercially oriented small- and midsize farms and a few (very) large farms. Employment in maize sector is estimated at 23 million jobs (mainly self-employment), of which 10% in midstream activities. The maize market is divided between informal and formal segments: most smallholder maize is used for milling and consumed locally, whereas midsize and large farms supply maize to larger (peri-)urban markets in the South. Margins in production and processing are attractive, but trade margins are thin due to strong competition.

Table 2 presents an overview of the main characteristics of each of the value chains with respect to input intensity, market orientation, scale of operations and value chain organization.

There is considerable variation in the configuration of midstream sector structures. Production of commodities such as cotton (Ethiopia) and cocoa (Cameroon) is still fairly extensive and involves limited prospects for value added creation. Commercial crops oriented towards local processing for regional and export markets (green beans in Kenya; sorghum in Ghana) rely on more intensive technologies, mainly to safeguard quality and freshness. On the other hand, production and processing activities in food staples (maize in Nigeria, groundnut in Ghana) oriented towards local and national markets are usually characterized by low or mediocre resource-intensity. For almost all products, firms engaged in midstream value chains include both small-scale self-employment enterprises as well as more formal

SMEs. These businesses mostly co-exist (mixed) or are mutually connected (differentiated), but in some countries, this is controlled by government regulation (Ethiopia) or contracts (Kenya; Cameroon).

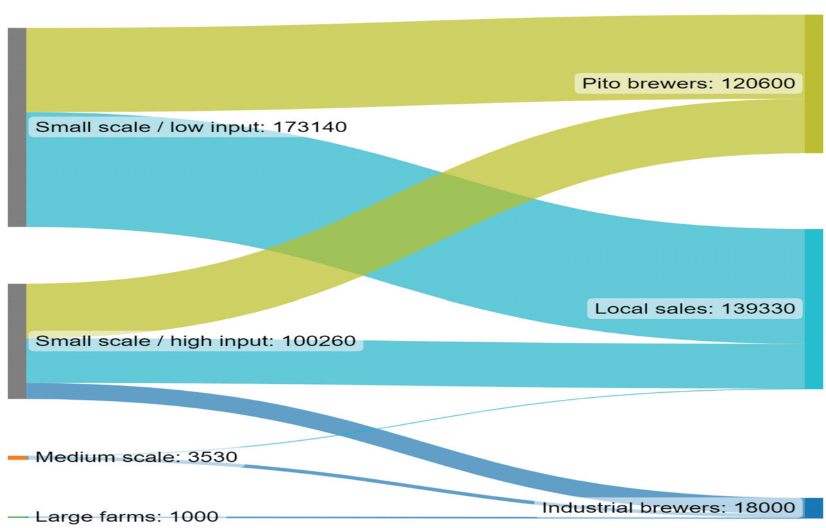
Table 2. Comparison of midstream sector structure and market dynamics.

Commodity	Country	Input Intensity	Market Outlets	Production Scale	Value Chain Organization
Cocoa	Cameroon	Low	Export	Mixed	Contracts (cooperatives)
Cotton	Ethiopia	Low	National	Medium	Contracts (controlled)
Green beans	Kenya	High	Export	Large (Industrial)	Contracts (processors)
Sorghum	Ghana	Medium	Regional	Small	Differentiated (informal aggregators and processors)
Groundnut	Ghana	Medium	National	Small	Differentiated (informal traders)
Maize	Nigeria	Low	Local	Small	Spot exchange

Notes: mixed (scale) refers to co-existence of firms with different scales of operation; differentiated (VC organization) refers to simultaneous linkages to multiple agents.

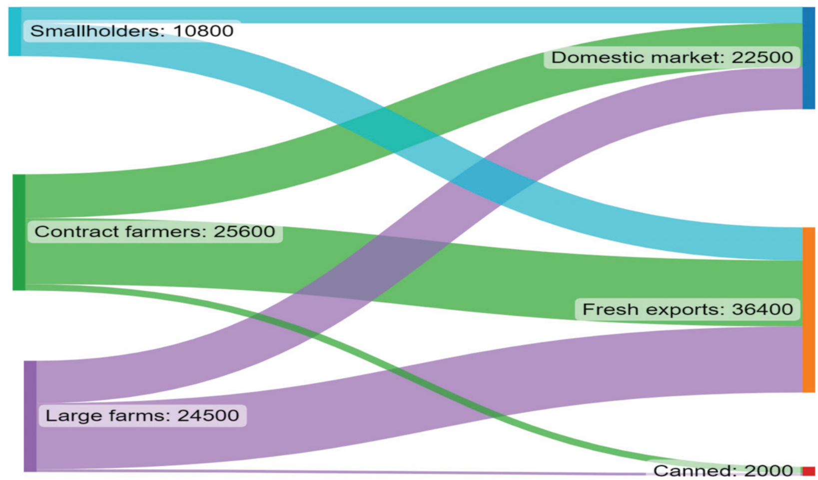
2.4. *Archetypes of Production—Market VC Linkages*

The commodity flows between primary producers and midstream agents can be illustrated with Sankey diagrams that show the origin and destination of products]. Three typical archetypes of VC can be distinguished (see Figure 3a–c):

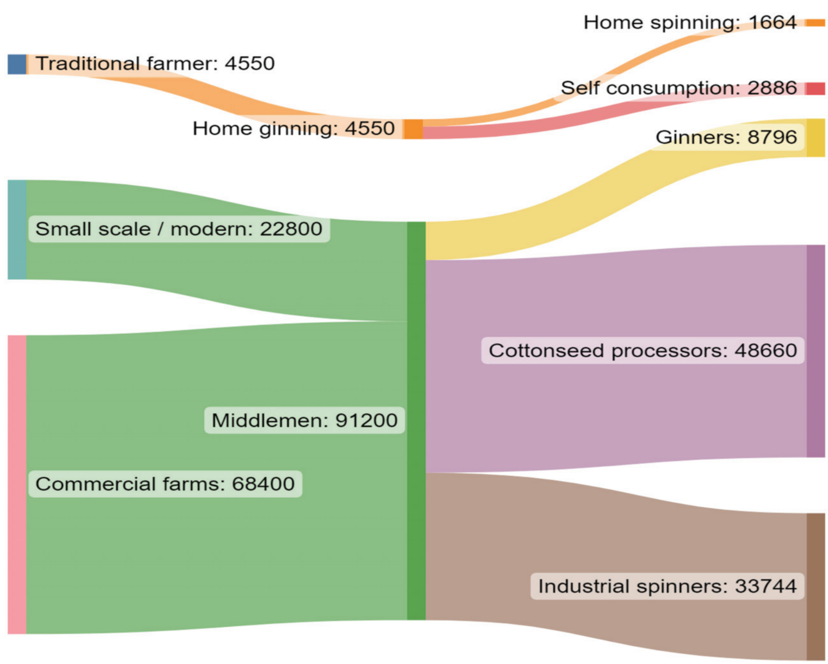


(a)

Figure 3. *Cont.*



(**b**)



(**c**)

Figure 3. (**a**) Smallholder-dominated VCs: sorghum in Ghana. (**b**) Bi-modal VCs: green beans in Kenya. (**c**) Large-scale dominated VCs: cotton in Ethiopia.

The sorghum value chain (Ghana) connects a large number of scattered smallholder producers with highly decentralized artisan pita brewers (processors) and local markets (direct sales to consumers). Average traded volumes are limited and competition is strong (due to low entry costs), leading to relatively small margins for traders. A small number of industrial brewers organize their sourcing from medium-scale and large farms, but also purchase from small-scale producers.

In the green beans value chain in Kenya, smallholders working with and without delivery contracts deliver products to a few packhouses and canning factories. Half of the production is exported as fresh or canned/frozen beans, whereas the other half is for domestic consumption, animal feed and compost. A few large farms control 45% of market supply and are mainly export-oriented (of fresh, canned and frozen beans), but their sub-standard products are sold locally.

The cotton sector in Ethiopia is dominated by a few large commercial farms that are linked through selected middlemen with a cluster of industrial spinners and cottonseed processors. Small traditional cotton farmers are linked only to local outlets. These two market segments coexist but hardly interact, mainly due to large differences in scale of operations, quality norms and investment requirement.

3. Results

In this section, we present an overview of the comparative performance of the six agri-food VCs and the implications of differences in midstream organization for primary production systems. First, we look at the structure of primary production and the smallholder contribution to the production value and the marketable surplus. Second, we assess the linkages between primary production and midstream VCs, especially looking at the importance for the creation of (wage) employment and the generation of value added. Third, we analyse the impact of midstream development (in terms of value added share) on the primary production structure and the implicit incentives for factor use intensification.

3.1. Structure of Primary Production

Smallholders play a dominant role in many agricultural production systems. They have a comparative advantage for more labour intensive crops [26], because they can mobilize flexible amounts of (family) labour for seasonal operations (land preparation, harvesting). Medium-scale farms are becoming more important for input-intensive production systems with higher quality standards. Large scale farms appear when economies of scale and scope arise.

Figure 4 shows important differences in the farm size structure between the six value chains [27]. We define small-scale as between 0 and 3 hectares, medium-scale as between 3 and 20 hectares, and large scale as above 20 hectares. However, within each size-category there is considerable variation in average farm size. The average "large-scale farm" in the cocoa sector of Cameroon has 25 hectares, for example, while the average "large-scale" farm in the cotton sector of Ethiopia has over 400 hectares. In countries like Ghana (sorghum and groundnut) and Cameroon (cocoa), smallholder farmers contribute 90% or more to the total value of production, whereas in Kenya (green beans) and in Ethiopia (cotton) large farmers are particularly important for the generation of marketable surplus. This confirms the trend that smallholders maintain a comparative advantage in staple production for local outlets linked to consumer markets (sorghum and groundnut in Ghana) or for direct processing (cocoa in Cameroon), whereas midsize and large firms become more important for food deliveries to urban conglomerates (maize in Nigeria), semi-industrial processors for national markets (cotton in Ethiopia) or export markets (green beans in Kenya).

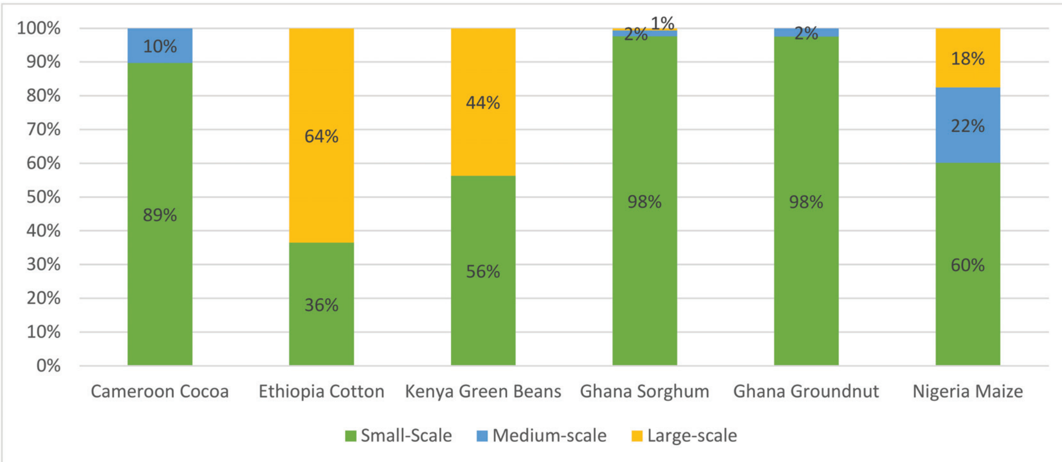


Figure 4. Contribution of different farm categories to total production value by primary sector.

The intensive linkages between producers and processors through procurement contracts (green beans in Kenya) or other delivery arrangements (cotton in Ethiopia) create space for larger companies that are better able to guarantee continuous deliveries and standard quality norms. For cocoa (Cameroon) deliveries of raw material is still mainly dominated by smallholders that rely on fairly traditional production systems. Their production is committed to traditional small-scale local processors through input delivery contracts (seedlings, fertilizers) and pre-finance arrangements.

These differences in the structure of primary production are reflected in the prices received by different farm sizes. Larger farms receive up to a 40% higher farm-gate price compared to medium size farms, and this rises to 75% higher prices compared to those paid to smallholder producers. This implies that differences in production size are translated into even higher discrepancies in value added distribution between small and large producers.

3.2. Importance of Midstream VC

Whereas primary agricultural production has been traditionally responsible for a major share of rural (self- and wage-)employment and value added, the importance of midstream enterprises is gradually increasing and some agri-food VCs are becoming more oriented towards employment creation and value added generation in downstream segments [28] [1]. We present the value added and employment structure of the six VCs (Figure 5) and distinguish three different structural patterns: (a) VCs where employment and value added are dominated by midstream agents (groundnut and sorghum in Ghana), (b) VCs where primary production still dominates employment and value added (maize in Nigeria, and—to a minor extent—cotton in Ethiopia) and (c) mixed or bi-modal VCs (green beans in Kenya, cocoa in Cameroon) where the midstream controls a major share of value added but primary producers still dominates employment generation. Figure 3a–c show the structure of material commodity flows between primary producers and midstream agents illustrated with Sankey diagrams that characterize the origin and destination of products.

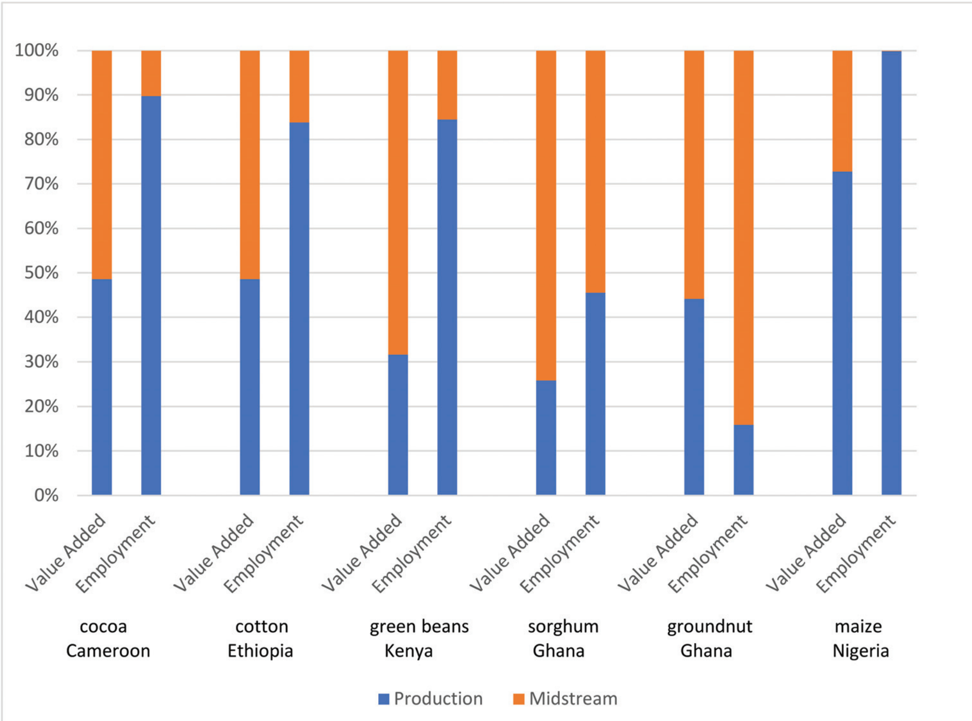


Figure 5. Employment and value added in primary production and midstream VCs.

The importance of midstream activities is usually larger in value added creation than in employment generation, with the sole exception of groundnut (Ghana) that relies on very labour-intensive and informal local processing. Production systems with many smallholders (maize in Nigeria, cocoa in Cameroon and cotton in Ethiopia) keep a large share of employment in primary production. Rising opportunities for downstream value added creation (such as for sorghum in Ghana and green beans in Kenya) give room for a market-oriented transition in VCs where midstream value added shares rise faster than the midstream employment share. Sorghum and groundnut (both in Ghana) show an opposite pattern of midstream expansion, with a higher value added share in sorghum VCs compared to a higher employment share in groundnut VCs. This is mainly related to the larger local processing options in sorghum and the very extensive character of groundnut cultivation that leaves little room for employment creation.

The structure of value added distribution within midstream operations is also quite different (see Figure 6). In the food staple VCs (maize, groundnut and—to a minor extent—sorghum) the recollection of the produce at farm gate and its storage and transport to local markets still represents 15–30% of value added. There is a dominant role of processing activities in value added creation for VCs of cotton (Ethiopia), green beans (Kenya) and sorghum for beer brewing (Ghana). In groundnut and cocoa VCs, a relatively high share of value added share remains with wholesale traders and distribution agents that are responsible for linking local producers and processors to larger wholesale traders and exporters.

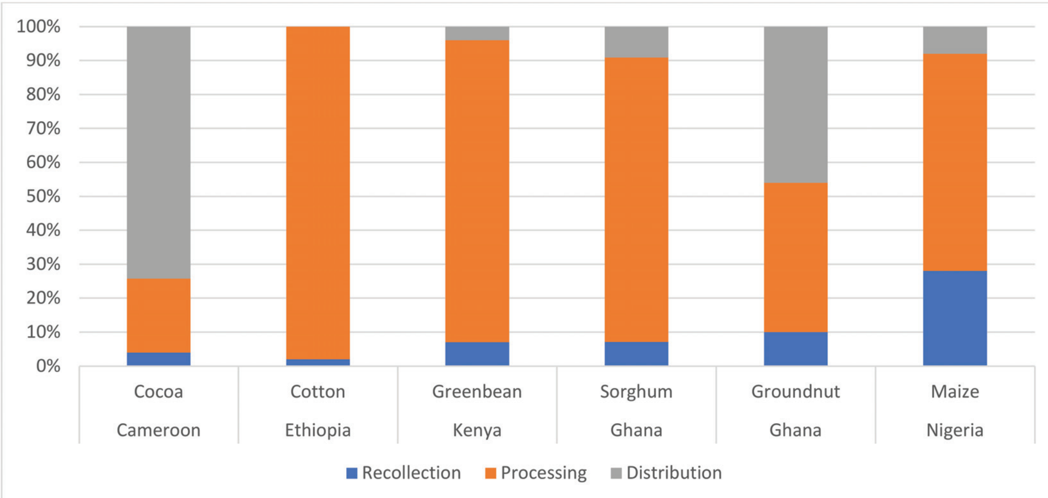


Figure 6. Composition of midstream value added distribution.

3.3. Relationships between the Midstream Value Chain and Smallholder Production Systems

Growing importance of midstream agents in the generation of value added may create (dis)incentives for smallholder investments in production system intensification, as discussed in the introduction. Both input intensity (use of intermediate inputs) as well as capital intensity (depreciation of capital stocks) in primary production are negatively associated with the value added share captured by midstream agents and, thus, positively associated with the value added share captured by primary production (see Figure 7). This is particularly the case for more intensive primary production systems of green beans (Kenya) and cocoa (Cameroon) that require large amounts of inputs and capital which translate into a lower value added share that can be realized in midstream operations. On the other hand, more extensive cropping systems in crops like sorghum and groundnut (Ghana) and cotton (Ethiopia) tend to lose a larger share of value added to competitive midstream agents.

This can also be explained by mechanisms that run in opposite direction but are, in fact, mutually reinforcing. Input and capital might increase production volumes and production quality. Higher quality in itself is a way to increase value addition, but higher volumes and higher quality can also increase the access to remunerative markets and improve the farm sector's bargaining position, leading to a larger value added share vis-à-vis the midstream. The causal mechanism might also run in the opposite direction: a lower value-added share in the midstream sector might be an indication for weaker bargaining power and might provide an incentive for farmers to invest in production because they are able to retain a large portion of the surplus generated.

The interaction between factor intensity and value added distribution at different levels of the VC provides important opportunities for the design of appropriate strategies towards smallholder intensification. Constraints of input and capital intensity in primary production are easily translated into deficiencies in midstream VC competitiveness. Otherwise, investments in input use and capital at the level of primary production improve competitiveness with midstream operations and enable smallholder farmers to retain a larger share of value added.

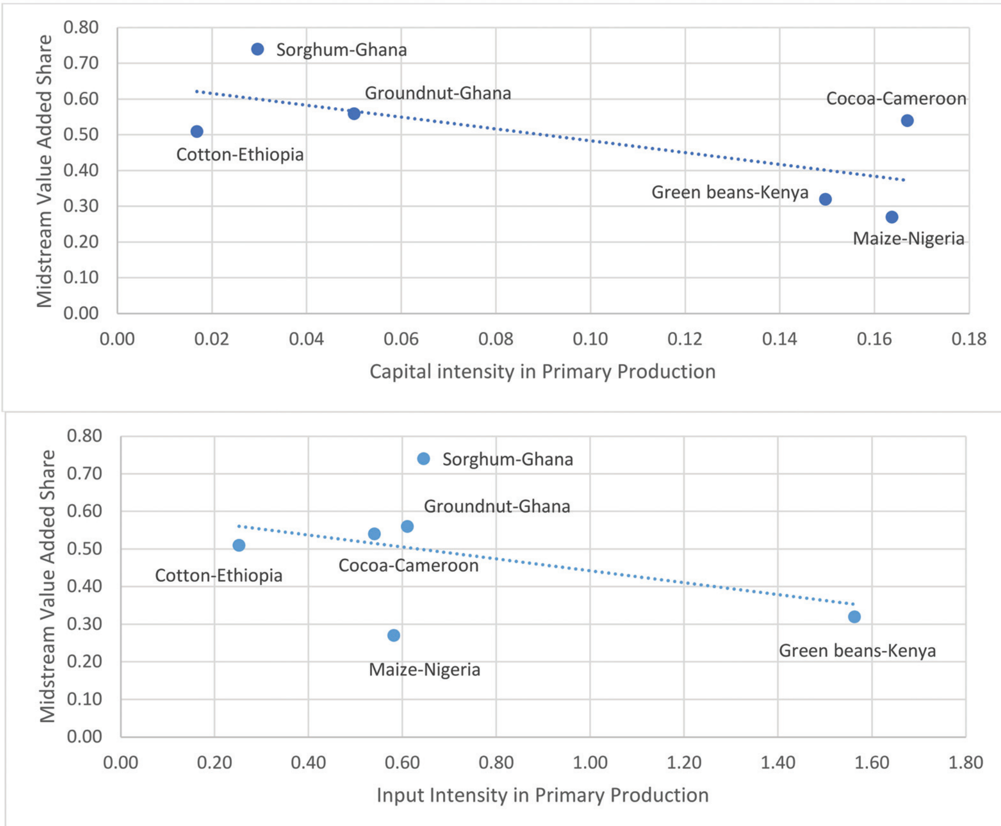


Figure 7. Factor intensity of primary production systems by midstream value added share.

Factor intensity not only depends on particular crop requirement, but is also related to the external production environment [27]. Countries with a higher degree of urbanization (Ghana, Cameroon), with more infrastructure facilities (Ghana, Kenya) and a better business climate (Nigeria, Ethiopia) enable midstream agents to capture a large value added share.

Additionally, value chains that require large investments of capital resources (compared to their output value) in midstream operations show to be able to capture a substantially larger midstream value-added shares (see Figure 8) as a compensation for these efforts. Products that require more investments for direct local processing (cocoa in Cameroon and sorghum in Ghana) are able to realize a larger VA share in midstream activities, while commodities with simple processing requirements (green beans in Kenya) receive a lower VA share for midstream activities. This can, again, be explained by mechanisms that run in both causal directions and that are mutually reinforcing: (1) the application of capital has a positive effect on quality and volumes, leading to more bargaining power and a higher value-added share; and/or (2) a higher value added share is related to higher bargaining power, which provides an incentive for investing more capital.

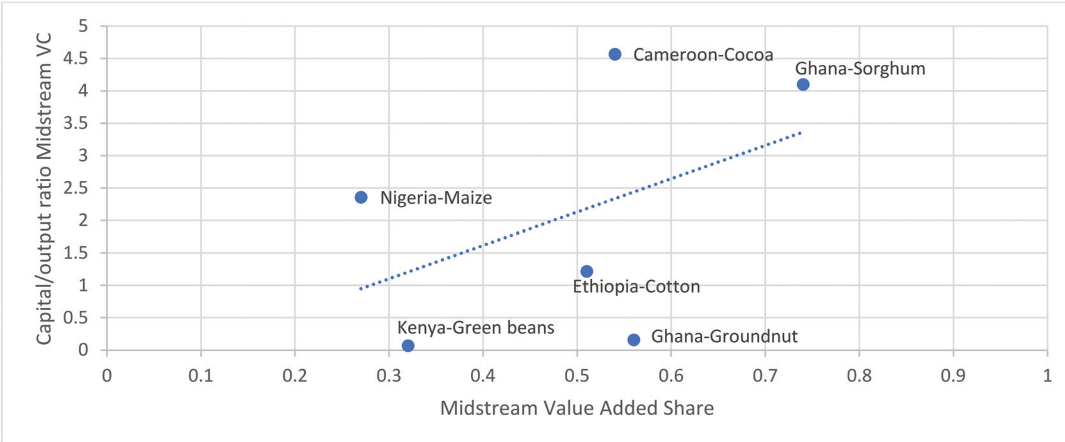


Figure 8. Capital intensity of midstream operations compared to midstream value added share.

In summary, we notice that smallholder producers involved in VCs with a high midstream value added share are less inclined to invest inputs and capital resources in the primary production stage. However, intensification of primary production may be considered as a relevant strategy to counteract the unrestricted value added capture by midstream agents.

3.4. Midstream Value Chains and Farm Size Structure

The relative importance of primary production by farmers and midstream activities undertaken by trading and processing firms is reflected in the value added shares realized in each of these VC stages. This also reflects the relative bargaining power of farm vs. firm operations that shape market exchange conditions. Smallholder farmers will be better able to engage in intensification of their production processes if they can reap the benefits of their investment. Otherwise, large VA shares for primary producers can be realized in markets where contractual delivery arrangements prevail (green beans in Kenya and cocoa in Cameroon). In both cases, market competition is based on quality compliance and therefore producers receive price incentives. Consequently, opportunities for maintaining smallholder farming systems are closely linked to the trade and investment opportunities provided by midstream stakeholders.

Figure 9 shows the relationship between the importance of midstream firms (expressed as the share of total value added) with the farm size structure (using the Gini ratio as indicator for relative inequality of the production value amongst farms) [27]. A larger value added share generated outside primary production is associated with a more balanced farm size distribution (Gini < 0.3) and a growing space for family and midsize farms. This is likely to be based on more standardized primary production systems with easy entry that focus on high volume and rapid turnover in midstream operations. When the role of midstream agents in value added production becomes smaller, smallholder farming remains dominant but farm size inequality tends to become higher (Gini > 0.5). This may be due to higher quality requirements that ask for careful attention in primary production.

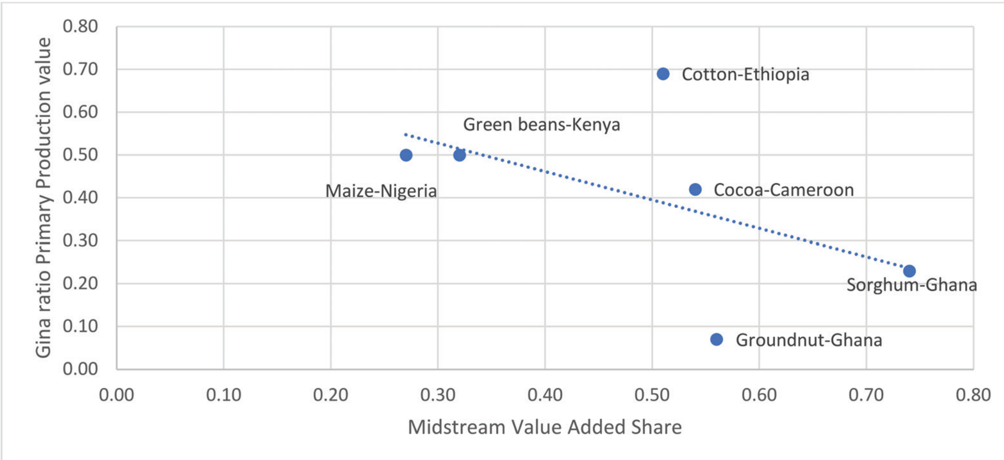


Figure 9. Midstream value added and farm size distribution.

We can now look at the implications of the before-outlined differences in primary production systems and their linkages to midstream operations for the farm size structure. As expected, we find higher farm size inequality in more commercially oriented commodities with strong bimodal VCs, such as in Ethiopia (cotton) and Kenya (green beans). The high Gini ratio for maize in Nigeria is explained by the important segment of midsize and large farms that are responsible for supplying maize at scale for large (peri-)urban markets in other regions. On the other hand, food staple crops (sorghum and groundnut) in Ghana maintain a more balanced farm size distribution since their output is usually sold through a large number of midstream traders at nearby local or sub-regional markets. Cocoa production (Cameroon) is an intermediary case where post-harvest midstream operations are particularly important for guaranteeing quality through adequate drying, fermentation and packaging, but primary production remains largely dominated by smallholder farmers that are fairly well organized and maintain a rather strong bargaining position.

This general picture seems to indicate that development of input and output markets (that lead to increasing midstream value-added creation) could be a helpful strategy to support a more equitable farm size distribution (even while we have no proof of causality). Smallholder farms dominate the production and marketing of many staple food crops (maize, sorghum, groundnut) that are both used for local consumption and (peri-)urban processing. Larger farms dominate the production of highly commercial activities such as green beans (Kenya) and cotton (Ethiopia). Cocoa appears as a typical case of a smallholder-dominated crop with high commercialization rates where total value added is distributed equally between the production and the commercialization/processing stage.

This pattern roughly confirms earlier findings that midstream firms are critical for providing key services (i.e., input supply, technical assistance, service contracts, etc.) to smallholder producers [29]. Consequently, efforts to develop midstream enterprise activities can be supportive for the viability of small-scale (commercially oriented) producers. Average farm sizes are indeed increasing in most middle-income countries and emerging economies, including several East and Southern African countries [26]. More detailed country studies confirm that the share of land accounted for by marginal small-scale (0–2 hectares) holdings is generally declining in most sub-Saharan African countries, whereas medium-size farms (2–20 ha) are gradually becoming more important, both in terms of cultivated area and in terms of contribution to (commercial) crop production [30]. The number of mid-size farms is growing rapidly and medium-scale farms will soon account for the majority of operated farmland and generate a growing share of the marketable food in many African countries.

4. Discussion and Conclusions

Recent developments in the organization and governance of agri-food value chains in sub-Saharan Africa show a remarkable dynamics in terms of labour allocation, investments, trade transactions and value added distribution. We used primary data from six typical agri-food chains to assess the implications of the growing importance of midstream operations for the competitive position of smallholder farmers, in order to better understand the opportunities and constraints for value chain-driven strategies towards agricultural intensification.

We therefore analysed the relationships between productions systems, value chain organization and farm size structure. This analysis is based on the idea that the structural farm-size composition is a reflection of the competitive relationships at land, labour, capital and commodity markets [31]. Typical farm size structures emerge in response to opportunities for intensifying market linkages (efficiency and scale economies) and for upgrading factor productivity (through innovations that influence crop and technology choice and improve quality performance).

Smallholder farms play a critical role in the absorption of rural labour, but midsize farms are better able to respond to market challenges. Growing opportunities for mechanization and standardization may eventually lead to further farm concentration. Many smallholders only produce a small surplus and therefore the marketed volume is exceedingly concentrated among a small group of medium-size and large producers [32]. This is a reason to question the exclusive commitment to smallholders and argue for a much more open-minded approach to midsize producers [33].

The analysis in this article focuses on two research issues. First, we looked at the role of smallholder linkages with commercial midstream value chains actors and their implications for investments in improving farm-level efficiency and factor productivity. We find that midstream activities become increasingly important for value added generation, even while in smallholder-dominated VCs primary production keeps a major share of employment creation. Rising opportunities for downstream value added generation give room for a market-oriented transition in VCs where the midstream value added shares rises faster than the midstream employment share. VCs with larger opportunities for local processing and/or more extensive cultivation practices leaves more room for midstream employment creation.

The growth of midstream value added has profound effects on farm-level operations. Investments in better input use and capital at the level of primary production lead to improved competitiveness with midstream operations and enable smallholder farmers to retain a larger share of value added activity. Prospects for intensification in primary production increase when the value added share captured by midstream agents remains restricted. More intensive primary production systems that require larger amounts of inputs and capital realize a lower value added share in midstream operations, while more extensive cropping systems tend to transfer a larger share of total value added to competitive midstream agents.

Second, we assessed the importance of value added generation in midstream value chain segments for composition of the farm size structure in primary production. Contrary to our expectations, we find that a larger value added share generated in midstream operations is associated with a more balanced farm size distribution. This is mainly due to the growing importance of quality compliance operations in primary production. Smallholders meet prospects in VC integration that relies more on value added than just larger volumes. This implies that further deepening of trade, processing and wholesale/retail activities can be beneficial as well for primary producers. These backwards linkages are particularly important in VCs of food staples and—to a minor extent—in cocoa, where local recollection and direct processing are critical for maintaining quality and reliability.

The growing interactions between smallholder production and midstream operations have profound implications for the design of policies and programs aiming at VC intensification. Whereas most traditional rural development focus on 'push' incentives (training, credit, extension), it appears that smallholders' decisions towards farming system intensification depend far more on the prospects for engaging in rewarding value-chain linkages and procurement contracts with midstream agents. These 'pull' incentives from VC partners are critical for reducing risks and transaction costs that are required to enhance the likelihood of investment decisions.

Further research on the linkages between midstream VC development and the competitiveness of smallholder producers should focus attention on the (technical) opportunities for improving the input efficiency of primary production systems and the (economic) strategies for enhancing the profitability of value chain operations. Therefore, due attention needs to be given to the possibilities for strengthening the potential for greater reliance on contractual arrangements strategies for reducing transaction costs.

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Data Availability Statement: All primary data is included in the country reports published at the VCA4D website (https://europa.eu/capacity4dev/value-chain-analysis-for-development-vca4d (accessed on 22 January 2022).

Conflicts of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Notes

[1] It should be noted that employment data are usually restricted to salaries paid for wage employment, whereas self-employment and unpaid family labour are underestimated. The same holds for the registration of value added that tends to be restricted to market-based transactions and therefore underestimates the production used for home consumption and/or for informal local exchange transactions.

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Lives and Livelihoods in Smallholder Farming Systems of Senegal: Impacts, Adaptation, and Resilience to COVID-19

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Abstract: The COVID-19 pandemic has had immediate and cascading impacts on global agricultural systems. In Senegal, the immediate impacts include inaccessibility of inputs due to disruption in markets and supply chains, availability of labor, and changes in crop and livestock management practices. To understand the range of impacts on the biophysical and socioeconomic dimensions of smallholder farming systems, a survey was designed to identify the risk factors, assess the impacts, and explore appropriate mitigation strategies. The survey was administered to 917 smallholder farmers in 14 regions of Senegal in collaboration with a national farmer's organization and the Senegalese Institute of Agricultural Research (ISRA). The sample was comprised of farmers (men and women) and was stratified in each region to ensure representation from all agroecological zones of the country. The survey examined variables such as access to inputs, ability to plant, impacts on yields, markets, labor, the gendered division of labor, food security, and community well-being. The survey response indicated that 77.7% of respondents experienced a reduction in access to inputs, 70.3% experienced a reduction in ability to plant crops during the planting season, 57.1% experienced a reduction in ability to rent farm machinery, and 69.2% reported a reduction in yields. Similar findings were observed for labor, market conditions, and adaptation measures to reduce the impacts on farming systems and household livelihoods. This study advances the research on characterizing risk factors, assessing the impacts, and designing mitigation strategies for strengthening smallholder farming systems resilience to future shocks.

Keywords: food insecurity; livestock; labor; markets; gender equity; agricultural supply chain; mitigation

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1. Introduction

An understanding of the multi-faceted drivers of smallholder farming systems lies in contextualizing the assessment of the current status and trajectory of change. These drivers include demographics, markets and institutions, climate, and geopolitical issues [1]. Rural smallholder households adopt indigenous strategies to cope with short term changes as a self-regulatory mechanism [2]. African smallholder farming systems are impacted by abiotic and biotic stresses, and a cycle of poverty due to myriad factors. Attempts to improve the livelihoods of smallholder farmers in this region often fail due to a focus on maintaining equilibrium among all dimensions of farming systems [3]. In Senegal, agriculture is an important indicator of the rural economy and hence worthy of examining.

In March of 2020, Senegal witnessed the rapid transmission and spread of the global COVID-19 pandemic, which risked both the lives and livelihoods of smallholder farmers. The mobility restrictions and border closures had severe impacts on livelihoods, and the cascading impacts are yet to be assessed [4]. The inaccessibility of inputs and labor impeded farm decisions and operations [5]. The impacts of COVID-19 on all components of agricultural systems make the outcomes unpredictable. Smallholder farming systems of Senegal embody systemic diversity in terms of the dynamic interplay among socioeconomic and biophysical drivers, which pose a challenge in assessing the impact of shocks such as COVID-19. Given that the pandemic is relatively recent, empirical research on the impacts of COVID-19 is still emerging, though some survey research has been published [6,7].

As the pandemic progressed, researchers across the globe started reporting the impacts on smallholder farming systems with a focus on food security and farming systems resilience [5]. The perceptions of smallholder farmers in Senegal were recorded through surveys highlighting the negative impacts on their livelihoods due to fractured supply chains and the disrupted market [6]. Moreover, extrapolating using a simulation model, Jha et al. [8] highlighted the impacts of reduced planting area and yield decreases on national gross domestic product (GDP). Government and development agencies developed several initiatives to mitigate the impacts of the pandemic with a special emphasis on food and nutritional security of households and strengthening the microeconomics of smallholder households [9–14]. Despite these initiatives, none of the researchers tried to assess impacts at each layer of smallholder farming systems and connect these with needed policies to support and strengthen the resiliency of smallholder farming systems to shocks such as COVID-19.

The main objectives of this study were to explore the actual experiences of smallholder farmers in Senegal, how those experiences impacted their systems, and how farmers developed short-term adaptive capacities. We hypothesized that livelihoods of smallholder farmers in Senegal were negatively impacted due to mobility restrictions and disrupted supply chains. The results from this survey help to quantify the impacts of COVID-19 on the livelihoods of smallholder farming systems and to understand mitigation strategies and measures to strengthen and build resilience of these systems to better manage and prepare for future events of this scale.

2. Data and Empirical Strategy

2.1. Study Area

Senegal is situated in West Africa surrounded by four coastal countries—Mauritania in the north, Guinea in the southeast, Guinea-Bissau in the southwest, and Mali in the east. Moreover, Senegal completely surrounds The Gambia, which stretches along the Gambia river. Senegal has a dry tropical climate with a total land area of approximately 192,530 km^2, of which 16.6% (~3.2 million hectares) is arable land [15]. Administratively, the country has 14 regions (e.g., Dakar, Diourbel, Fatick, Kaffrine, Kaolack, Kédougou, Kolda, Louga, Matam, Saint-Louis, Sédhiou, Tambacounda, Thiès, and Ziguinchor) which are further subdivided into 46 provinces (Figure 1). The total population of Senegal is 17.5 million (2022), which consists of 49% male and 51% female [16]. One quarter of the population is concentrated around the capital region of Dakar (Figure 1), which is 0.3% of total land area.

2.2. Economy and Agriculture

The agricultural sector, which includes crops, fishing, forestry, hunting and livestock, is 17% of the total GDP of USD 24.9 billion and accounts for 30% of the total employed population in the country as of 2020 [16]. The agriculture sector covers 46% of the total land area. The country is classified into three agroecological zones based on latitudinal descent of rainfall from the south to the north, i.e., southern humid, central sub humid, and northern arid and semi-arid agroecological zones [17]. The main crops cultivated in the southern humid region are rice (*Oryza sativa* L.), pearl millet (*Pennisetum glaucum* (L.) R. Br.), and maize (*Zea mays* L.). In the central sub humid region, the main crops are cotton (*Gossypium hirsutum* L.), pearl millet, sorghum (*Sorghum bicolor* L. Moench) and maize. In the northern arid region, the predominant farming system is agropastoral livestock production with groundnut (*Arachis hypogaea* L.) as the major crop. The pastoral farming system consists of small family farms that occupy 95% of the country's agricultural land under rainfed cultivation in the northern arid and semiarid regions. Polyculture systems are followed in the irrigated peri-urban area of Dakar, which also supports commercial agriculture with horticulture and intensive livestock farming, with one percent of the working population and five percent of total agricultural land in the southern humid regions [18].

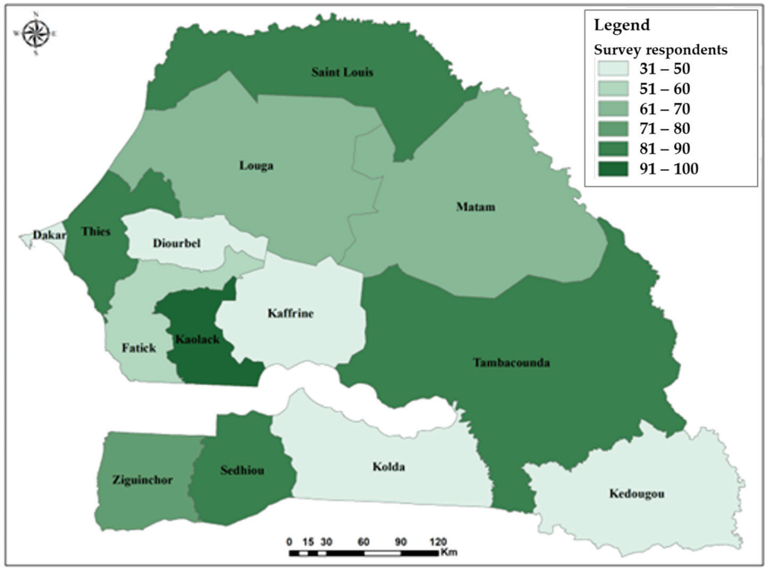

Figure 1. Administrative regions in Senegal and number of survey respondents in each region.

In 2017, the annual growth rate of GDP was 7.4% followed by steep declines to 6.2% in 2018, 4.4% in 2019, and 0.87% in 2020 [15]. The impacts of the pandemic significantly changed the economic outlook of Senegal, which relies significantly on food imports. Distorted supply chains due to fractured transportation, labor shortfalls, inflation, and price volatility, hit the informal sector the most [6]. As agriculture is the most dynamic engine of economic growth, there will be a fresh impetus to the gradual economic recovery if adaptation and mitigation strategies to reduce socioeconomic impacts are inclusive and sustainable [8].

2.3. Sample Population and Distribution

To assess the impacts of the pandemic on smallholder farming systems, a survey was designed and implemented following standard methods in the field [6,7,19]. The sample frame was drawn in collaboration with Reseau des Organisations Paysannes et Pastorales (RESOPP), a farmer organization that maintains a database of approximately 24,000 farmers, and the Senegalese Institute of Agricultural Research (ISRA). ISRA's research is primarily dedicated to developing and disseminating scientific agricultural research to smallholder farmers with the goal of achieving food security and reducing poverty. To be included in the survey, respondents needed to be smallholder farmers, head of household, and 18 years of age or older. The sample was stratified with farmers from each region to ensure representation from all agroecological zones of the country. The aim was to contact at least 65 farmers per region. This led to a total sample size of 917.

Local researchers from ISRA, who were well-versed with the farming systems, and the specific cultural context and language, administered the survey with the assistance of enumerators. Standard practices regarding consent and participation in the survey were followed. The survey design ensured that respondents were aware that their participation was voluntary and that they had the flexibility to withdraw from the survey at any time. It was also made clear that data would not be linked to individual respondents, thereby protecting the respondents' identity. The local enumerators were trained in best practices prior to administering the survey. Based on the telephone survey, enumerators entered the responses into the Qualtrics© survey system.

2.4. Survey Design and Timing

The survey was designed to capture the impacts of the pandemic on crop production practices and the livelihoods of farmers. Variables including access to inputs, ability to plant, impacts on yields, markets, labor, the gendered division of labor, food security, and community well-being were examined in the survey. The demographic questions helped in further analysis of the impacts on specific segments of the population. The survey design and the scale of responses are summarized in Table 1. Out of 917 individuals who were contacted to take the survey, 882 consented to participate and 35 opted not to take the survey; hence, a total response rate of 96%. The Qualtrics survey data and responses were analyzed using SPSS, a statistical software package.

Table 1. Summary of the survey design and questions.

Section Name	Question	Question Type(s)	Possible Responses
Consent	1.2	Willingness to participate	Will participate/will not
Farm Type	2.1	Crops, livestock, or vegetables	Yes/No
Agronomic and Biophysical Aspects of Cropping Systems	3.1–3.6	Main crops grown; production consumed at home; access to inputs; ability to plant, ability to rent machinery, yield reduction	Crop choices, % [1]; agreement [2] scale
Market Issues	4.1–4.3	Access to the local/urban markets; issues related to transportation, distributors, harvest loss, sales	Percentage (%) [1]; agreement [2] scale;
Labor Issues	5.1–5.6	Access to on-farm and off-farm labor; issues related to finances and availability of labor	Agreement [2] scale; availability scale [3], (%) [1] and open-ended
Impacts for Women and Youth	6.1–6.4	Perceptions of what might occur for women and youth due to COVID-19	Agreement [2] scale and open-ended
Agricultural Adaptations and Mitigation	7.1–7.9	Mitigation plans: COVID-19 impact; contingency plans if any	Yes/no and why; open-ended for impact and contingency plans
Livelihoods and Social Well-Being	8.1–8.5	Access to food, markets, purchases, cost of food, and labor; access to social services, farm credit, subsides, other financial support; challenges due do COVID-19	Agreement [2] scale; yes/no; and open-ended
Demographics	9.1–9.6	Relationship and activity with farmer organizations; age; gender; district; household size	Yes/no; amount of time; male, female, prefer not to say; age range; open-ended; household size
Agronomic and Biophysical Aspects of Livestock Systems	10.1–10.5	Main livestock raised; production consumed at home; access to inputs; Impact on raising, production reduction	Animal choices, % [1]; agreement [2] scale

[1] Percent choices were 0–25%, 26–50%, 51–75%, 76–100%; [2] Used a 5-point scale (1 = Strongly Agree to 5 = Strongly Disagree); [3] Used a 5-point scale (1 = Much less to 5 = Much more).

The survey was launched on 1 March 2021 and closed on 31 May 2021. The first case of COVID-19 in Senegal was reported on 2 March 2020. The local government-imposed mobility restrictions and border closures within two weeks of the onset. According to

World Health Organization data, total COVID-19 cases in Senegal were 88,832 and the associated death count reached 1968 (as of 14 November 2022).

3. Results and Discussion

3.1. Respondent Demographics

The socio-demographic characteristics of the respondents are highlighted in Table 2. The demographics revealed that the majority of the respondents were male (80.7%) with 19.2% female, and one respondent preferred not to respond to the gender question. The bulk of respondents were in the age range of 35 to 64 years (86.5%). In Senegal, the head of household is usually the eldest male, who manages common fields for family needs. Men generally grow cash crops and women take care of fruits and vegetables consumed at home or sold at domestic markets. For livestock, men take care of draft animals while women rear cattle and poultry. Adult members of the family work to maximize their income to support the household [20].

Table 2. Socio-demographic characteristics of respondents. Household size was on a 21-point scale, (1 = "1" to 21 = "More than 20"): Mean = 10.70, SD = 5.25.

Variable	Category/Description	Frequency (n = 866) (%)
Sex	Female	166 (19.2)
	Male	699 (80.7)
Age	18–24	1 (0.1)
	25–34	54 (6.2)
	35–44	224 (25.9)
	45–54	307 (35.5)
	55–64	217 (25.1)
	65–74	54 (6.2)
	75–85 or older	9 (1.0)
Household Size	1–5	163 (18.7)
	6–10	288 (33.2)
	11–15	282 (32.6)
	16–20	61 (7.10)
	More than 20	72 (8.3)

Household size is a strong determinant of resilience capacity of the family and can be measured through assets, savings, and credit. Allocation of resources and active participation in agricultural activities are two prime factors which were impacted by COVID-19 in rural households [21]. Household size ranged from "1" to "more than 20" family members per household, with an average size of ten. Most African countries have average household sizes greater than five. Senegal has one of the largest household sizes in the world [22]. Nébié et al. [23] reported that large households in Senegal are most vulnerable to food insecurity and poverty especially in less educated rural families.

The following sections describe the respondents' crop production, adaptations, mitigation activities, and issues related to markets, labor, women, and youth. The results also cover farmers' livelihoods, social well-being and household and community challenges.

3.2. Impact on Agriculture

Several reports have highlighted the impact of COVID-19-associated shocks on food production, supply chain disruptions, labor availability and food trade in Senegal [6,8,24–26]. In this study, we elaborate on the impacts on different components of agricultural systems based primarily on survey results. While there is a growing literature on building resilience in food systems [27–30], this survey brings insights into short-term and long-term resiliency of food systems to the specific case of COVID-19. Two-thirds (66%) of respondents grow primarily crops, whereas the remaining one-third (34%) practice diversified agricultural systems including livestock and horticulture. Van Hoyweghen et al. [26] have highlighted in their studies that diversified cropping systems, focused on modern export-centric cultivation, have more resiliency in overcoming COVID-19 associated shocks than the smallholder domestic demand-oriented growers, which were hindered by local mobility restrictions.

The survey results also showed that 13.4% respondents consumed less than one quarter of their total crop production at home, and they sold their produce to domestic markets, whereas 21.7% respondents consumed more than three quarters of their total crop production at home. The mobility restrictions due to the pandemic might be an important factor as to why they could not sell their produce locally [26]. Farm size is a significant determinant in farm-related decisions such as land use distribution among household members, adoption of technologies, improving resource use efficiency, and other associated costs leading to estimating their vulnerability to abiotic and biotic shocks [31,32]. More than 40% of respondents to this survey have average farm sizes of two hectares or less (Figure 2). Small farm size prohibits the household from large scale commercial cultivation, however small farms, if diversified, provide an economic trade-off, and offer better resiliency in the context of biophysical attributes and ecosystem services. Contrary to that, Van Hoyweghen et al. [26] reported that smallholder farms that were domestic demand-oriented faced local mobility restrictions and were less resilient to COVID-19 associated shocks.

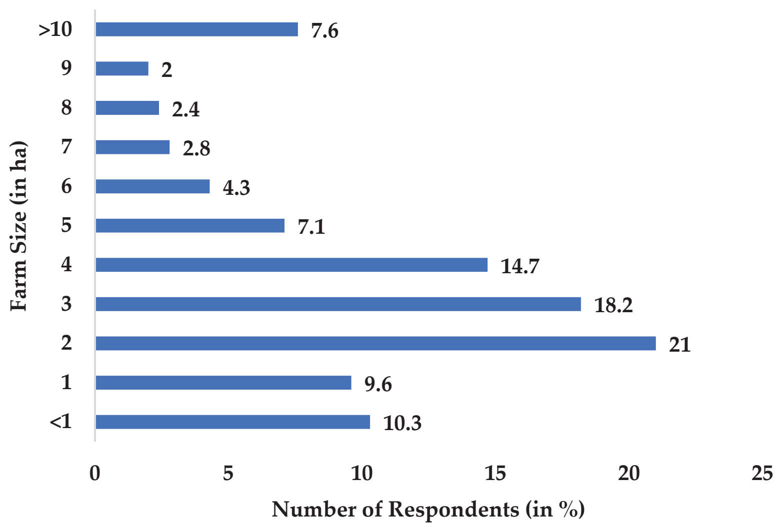

Figure 2. Farm size of survey respondents (*n* = 866).

3.2.1. Impact on Cropping Systems

The survey results represent the national crop distribution in Senegal [18], with the predominant crops being maize (55%), peanuts (49%), millet (48%), sorghum (32%), rice (27%), and tuber crops (9%). About 14% of respondents also included other varieties of fruits and vegetables captured in the survey as "Others", which are explained in the footnote (Figure 3). In addition to the ongoing agricultural research and development by several Senegalese agencies, the local government placed agroecological transition as one of the major initiatives in the Plan Sénégal Emergent (2019–2024), the key national policy framework that gives new impetus to expansion of cropping area with irrigation and other technological interventions [15]. The spread of the pandemic and associated restrictions hindered the pace of reform country-wide. Post-pandemic recovery will rely on the allocation of development funds to cropping intensification with a regular supply of inputs and technological interventions with the help of donors (e.g., Food and Agricultural Organization (FAO) (Rome, Italy), World Bank (Washington, DC, USA), United States Department of Agriculture (USDA) (Washington, DC, USA), and United States Agency for International Development (USAID) (Washington, DC, USA)) and the local government.

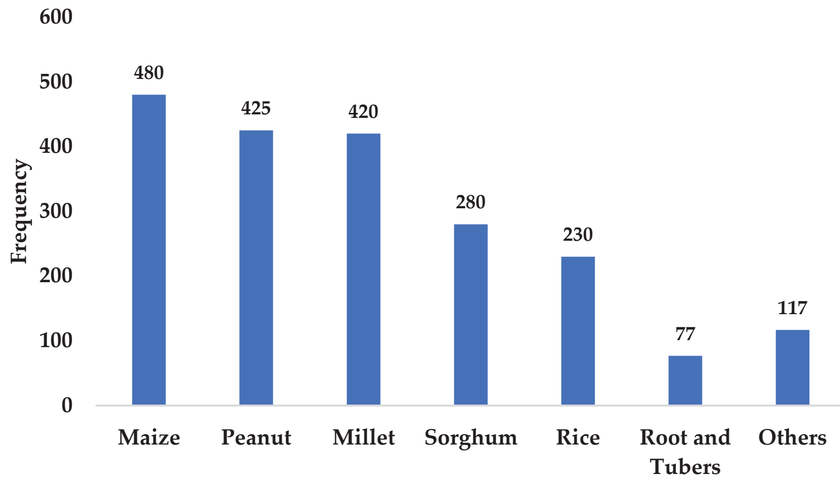

Figure 3. Main crops grown among survey respondents (n = 866). *Note:* Other responses described the following "other" crops: okra (n = 54), onion (n = 49), tomatoes (n = 48), chili (n = 33), eggplant (n = 29), cabbage (n = 19), hibiscus (n = 15), watermelon (n = 15), sorrel (n = 6), fonio (n = 7), cassava (n = 2), banana (n = 2), and wheat (n = 1).

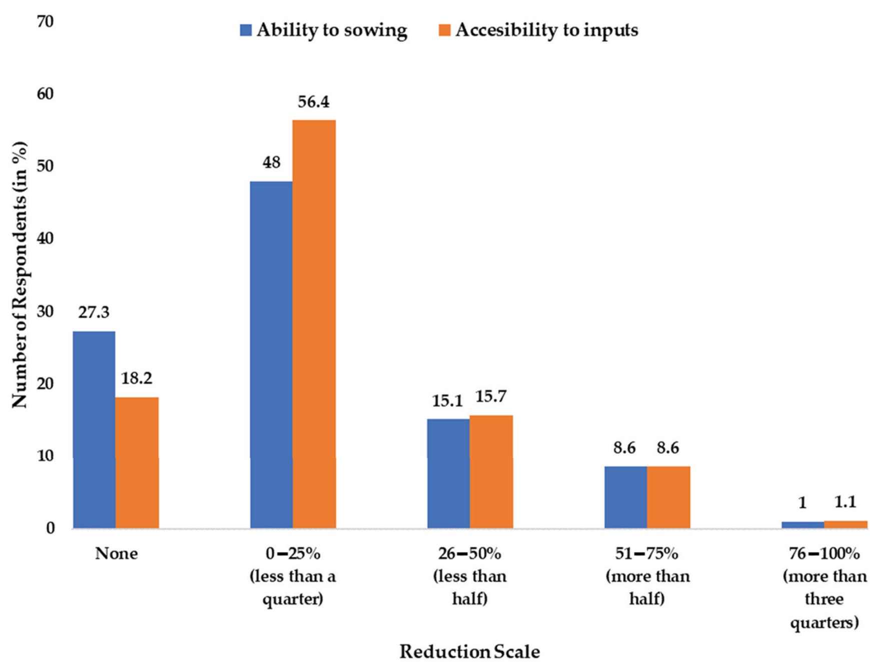

Figure 4. Reduction in ability to plant and accessibility to inputs among the respondents during the season (n = 802).

The pandemic drastically affected the availability of inputs due to mobility restrictions leading to the inability to plant crops during the growing season. The survey results indicate that 48% of respondents faced up to a 25% reduction in the ability to plant. More than 72% of the respondents reported some reduction in the ability to plant (Figure 4). The modeling extrapolation of the impact of reduction in planting area to the national level GDP of Senegal was explored by Jha et al. [8]. During the pandemic, Middendorf et al. [6]

did a survey on the expected impact on the reduction in planting area and found that 50% of respondents anticipated reduction in their ability to plant by ≤50%. The post-pandemic survey results concur with the survey of anticipated impacts during the peak period of the pandemic. However, median anticipation during the pandemic moved from less than half to less than quarter in the post-pandemic actual survey.

Table 3. Thinking about your experience of what has occurred due to COVID-19, please indicate your agreement or disagreement with the following statements. COVID-19 has . . . .

Statement	Strongly Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree	Total	Mean (SD)
Reduced my *access* to inputs (e.g., seeds, fertilizers, etc.) during this season.	77 (9.6%)	65 (8.1%)	38 (4.7%)	198 (24.7%)	424 (52.9%)	802	4.03 (1.32)
Reduced my ability to *plant* crops during this season.	82 (10.2%)	94 (11.7%)	63 (7.9%)	216 (26.9%)	347 (43.3%)	802	3.81 (1.36)
Reduced my ability to *rent* machinery during the planting season	95 (11.8%)	100 (12.5%)	151 (18.8%)	160 (20.0%)	296 (36.9%)	802	3.58 (1.39)
Reduced my crop *yields* in the harvest season.	76 (9.5%)	87 (10.8%)	85 (10.6%)	211 (26.3%)	343 (42.8%)	802	3.82 (1.33)

Note: Means are on a 5-point scale (1 = Strongly Disagree to 5 = Strongly Agree).

Table 4. How much of a reduction in crop yields per crop type (e.g., cereals, legumes, tubers) did you experience due to the impact of COVID-19 during this harvest season.

Crop Type	None at All	0–25% (Less than a Quarter)	26–50% (Less than Half)	51–75% (More than Half)	76–100% (More than Three Quarters)	Total	Mean (SD)
Cereals (Millet, rice, maize, sorghum)	369 (45.7%)	220 (27.2%)	158 (19.6%)	56 (6.9%)	5 (0.6%)	808	1.90 (0.99)
Legumes (Cowpeas, peanuts, beans)	161 (19.9%)	432 (53.5%)	151 (18.7%)	56 (6.9%)	8 (1.0%)	808	2.16 (0.85)
Root and Tubers (Potatoes, yams)	300 (37.1%)	287 (35.5%)	145 (17.9%)	68 (8.4%)	8 (1.0%)	808	2.01 (0.99)
Other types of crops not listed above	354 (43.8%)	210 (26.0%)	145 (17.9%)	73 (9.0%)	26 (3.2%)	808	2.02 (1.13)

Note: Respondents received this item if they indicated their farm was "primarily crops" or "diversified crops, vegetables, and livestock". Means are on a 5-point scale (1 = None at all to 5 = 76–100%). The Other responses listed the following crop types (13 of the responses listed multiple crop types): ras (n = 20), peanut (n = 15), market gardening (n = 7), jaxatu (eggplant) (n = 5), chili pepper (n = 5), tomato (n = 4), mil (n = 3), okra (n = 3), onion (n = 3), sweet eggplant (n = 3), pepper (n = 2), banana (n = 1), bissap (n = 1), cabbage (n = 1), corn (n = 1), cowpea (n = 1), legumes (n = 1), melon (n = 1), perte recolte (n = 1), and zucchini (n = 1).

Respondents were also asked about their experiences regarding their ability to plant, access to inputs, ability to rent farm machinery, and yield change at the end of the growing season. The responses indicated that 77.6% of respondents experienced a reduction in access to inputs, 70.2% experienced a reduction in their ability to plant crops during the planting season, 56.9% experienced a reduction in ability to rent farm machinery during growing season, and 79.1% reported a reduction in yields. These percentages are the aggregation of the two response categories "somewhat agree" and "strongly agree" (Table 3). The COVID-19 pandemic had an impact on crop production through its disruptive effects on input production, supply, and availability, leading to inordinate distortions of planting choice and calendars. Shrinking manufacturing capacity of chemicals and their distorted supply due to mobility restrictions led to reductions in access for farmers. Hence due to restricted availability of inputs, farmers could not manage biotic stresses for many crops leading to reduction in yields [21,25,33,34]. Unlike epizootic pandemics (e.g., avian flu, swine flu), which have direct impacts on livestock and produce, COVID-19 has indirect impacts on food production systems. Labor intensive food production systems require changes in management strategies such as staggered work shifts to avoid the physical concentration of workers with the goal of curtailing the transmission of virus and hence the cumulative impact on yield reduction. Surveys in

African counties revealed that young adults are less likely to be infected with the COVID-19 virus and are a major part of labor force in rural agriculture. [35]. Despite that, the loss in crop yields might be attributed to changes in planting and harvesting calendars, and unavailability of inputs and farm machinery.

The survey results show that there was some level of reduction in major crop yields. For example, 54.2, 80.3, 60.7, and 56% of respondents experienced reduction in yield for cereals, legumes, root and tubers, and others category respectively as illustrated in Table 4.

3.2.2. Impact on Livestock Systems

Livestock is an essential asset to rural smallholder livelihoods globally. West African arid agroecosystems are suited to livestock-centric agriculture and hence their contribution to GDP is more than 25% [36]. Livestock breeding is widespread in northern and central Senegal, especially Ranerou and Medina Yoro Foulah, where the pastoral farming system is widespread, indicated by the high percentage of households (60.2%) rearing livestock [37]. The survey results suggest that goats/sheep and cattle are two widespread types of livestock reared by respondents (Figure 5). Some also rear donkeys and horses, primarily for transportation purposes [38].

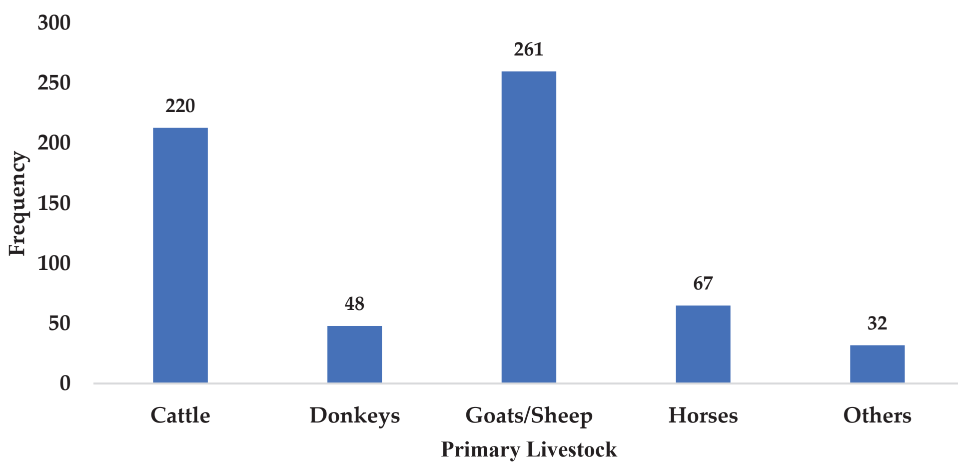

Figure 5. Primary livestock raised by respondents (n = 300).

The survey indicated that 76.5% of respondents experienced a reduction in access to inputs for livestock due to households facing a lack of access to markets and other extension services; 71.9% experienced a reduction in their ability to feed livestock during the season due to the disrupted markets and supply chains; 77.1% experienced a reduction in their ability to sell livestock during the season, and 44% reported an inability to rent draft animals for farm operations during the season. These percentages are the aggregation of the two response categories "somewhat agree" and "strongly agree" (Table 5). Decreasing consumer demand for animal products due to changes in diet patterns during the pandemic raised undue concerns associated with COVID-19, and unawareness led to disruptions in the livestock supply chain [39]. Therefore, the cumulative impact of feed shortage, lack of access to veterinary care, and deteriorating demand for animal produce during lockdown, led to a reduction in livestock production in Senegal. The decline in livestock productivity had a cascading impact on the microeconomics of households.

Table 5. Thinking about your experience of what has occurred due to COVID-19, please indicate your agreement or disagreement with the following statements.

Statement	Strongly Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree	Total	Mean (SD)
Reduced my *access* to inputs for my livestock (e.g., water, labor, feed, etc.) during this season.	20 (6.7%)	20 (6.7%)	30 (10.1%)	99 (33.5%)	127 (43.0%)	296	3.99 (1.18)
Reduced my ability to *feed* my livestock during this season.	31 (10.5%)	21 (7.1%)	31 (10.5%)	90 (30.4%)	123 (41.5%)	296	3.85 (1.31)
Reduced my ability to *sell* my livestock during this season.	20 (6.7%)	17 (5.7%)	31 (10.5%)	98 (33.1%)	130 (44.0%)	296	4.01 (1.17)
Reduced my ability to *rent* draft animals for farm operations.	25 (8.4%)	22 (7.4%)	119 (40.2%)	66 (22.3%)	64 (21.7%)	296	3.41 (1.15)

Note: Means are on a 5-point scale (1 = Strongly Disagree to 5 = Strongly Agree).

To ensure the resiliency of livestock production systems to the current and future pandemics, the region-specific preparedness, and mechanisms for recovery from disruption need to be addressed. Since livestock is an important component of food security in developing countries such as Senegal, research that can strengthen the understanding of how this system can become more resilient to meet food security objectives needs to be addressed. The government of Senegal has formulated short-term and medium-term plans to strengthen the livestock industry through technical support in disease and feed management, and financial support for investment in this sector with the goal of exporting livestock by-products [40].

Among the 300 respondents with livestock, 72.2% had more than 10 animals per household, and 82% of respondents used less than a quarter of the livestock production for home consumption. Culturally, livestock also serve as a status symbol in rural Senegal. Ownership varies with gender, as men usually own the draft animals and women own milk animals for domestic consumption. Moreover, if men control milk animals, they sell some proportion in the domestic market [20]. However, due to mobility restrictions, local markets were shut down, and therefore caused difficulties in selling of livestock for other consumables. Farmers sell or exchange cows and other livestock for life events such as weddings or other rituals [21,36]. In addition to their economic value, livestock also ensures the nutritional security of smallholder farmers [41].

Livestock production is vital for livelihoods and survival for smallholder farmers in the arid areas where the pastoral farming system is prevalent. Due to limited care to animals for forage and additive feeds, many farmers lost production during the pandemic. Accordingly, 66.1% of respondents experienced some reduction in livestock production. A reduced number of animals, home consumption, and reduction in production occurred. The reduction in livestock production during the pandemic can be attributed to several factors. Inaccessibility of livestock feeds due to disrupted supply chains was one of the main drivers of reduction in livestock production [21]. Moreover, due to the lockdown, the national vaccine campaign for Peste des petits ruminants (PPR) was suspended, local veterinary services were shut down, and this had a severe impact on livestock health, leading to reductions in production [42]. The limited availability of animal monitoring staff magnified the impact of livestock health on their productivity.

3.3. Impact on Socio-Economic Conditions

3.3.1. Impact on Markets and Supply Chains

The economic growth of Senegal increased from 2013 to 2017 due to the first phase of Plan Sénégal Emergent, the key national policy framework. However, from 2017 to 2020 annual growth in GDP declined from 7.4% to 0.87% [15]. In addition to these setbacks, another challenge of the pandemic struck Senegal in March 2020. To ensure the safety of citizens, several stringent measures were taken by the government that had impacts along the supply chain. Middendorf et al. [6] highlighted in their survey that 73.2% of respondents anticipated disruptions in local markets and supply chains. Our survey affirms those perceptions. Figure 6a shows that 72.8% of respondents experienced difficulty in accessing markets at different scales.

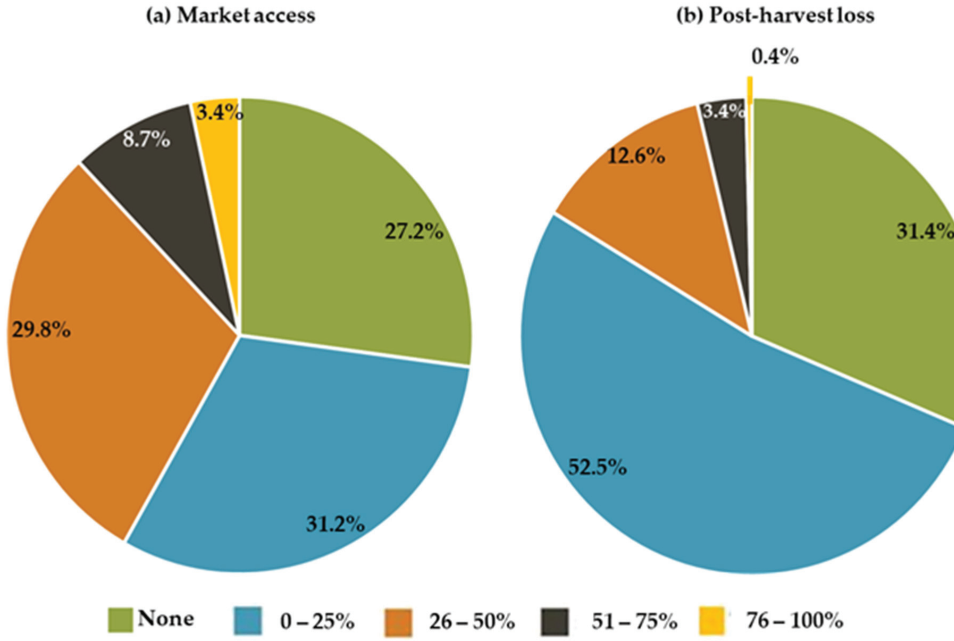

Figure 6. Share of crop production sold at market (**a**), and post-harvest loss (**b**), due to COVID-19 among respondents (n = 802).

The survey indicates that only 27.2% respondents did not experience difficulties with local farmer's markets. When we analyze and compare the share of crop production consumed at home with market accessibility (Figure 6a), we find that those who did not consume the share of production at home, either could have sold to the local market by securing supply for pre-season contract with dealers, or they might have faced post-harvest losses (Figure 6b) [21]. For horticultural or other perishable produce, post-harvest loss could mainly be due to the lockdown [26]. According to the survey, 68.6% respondents experienced crop production loss due to post-harvest issues (e.g., spoilage, spillage, overage) due to COVID-19.

Table 6. Thinking about your experience related to market issues, please indicate your level of agreement or disagreement with the following statements. COVID-19 has . . . .

Statement	Strongly Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree	Total	Mean (SD)
Reduced access to getting my produce to the *local* market during this season.	34 (4.2%)	33 (4.1%)	49 (6.1%)	185 (23.1%)	501 (62.5%)	802	4.35 (1.05)
Reduced access to getting my produce to the *urban* market during this season.	30 (3.7%)	21 (2.6%)	60 (7.5%)	213 (26.6%)	478 (59.6%)	802	4.36 (0.99)
Reduced my ability to *transport* my produce to the market during this season.	25 (3.1%)	24 (3.0%)	59 (7.4%)	171 (21.3%)	523 (65.2%)	802	4.43 (0.97)
Reduced the number of *distributors* for my produce during this season.	43 (5.4%)	41 (5.1%)	108 (13.5%)	184 (22.9%)	426 (53.1%)	802	4.13 (1.15)
Increased *post-harvest loss* during this season (e.g., spoilage, lack of cold storage).	54 (6.7%)	73 (9.1%)	92 (11.5%)	176 (21.9%)	407 (50.7%)	802	4.01 (1.26)

Note: Means are on a 5-point scale (1 = Strongly Disagree to 5 = Strongly Agree).

Table 6 indicates that 85.6% and 86.2% of respondents experienced a reduction in access to getting their produce to local and urban markets, respectively, during the 2020 growing season. Mobility restrictions were the prime reason for this difficulty. Transport to local markets is done by donkeys and horses in rural Senegal. However, due to restrictions, 86.5% of respondents experienced a reduction in their ability to transport their produce to the market, 76% experienced a reduction in the number of distributors for their produce during this season, and 72.6% reported increased post-harvest loss (e.g., spoilage, and lack of cold storage) during the 2020 growing season. These percentages are the aggregation of the two response categories "somewhat agree" and "strongly agree." (Table 6).

3.3.2. Impact on Labor Availability

The supply and demand for labor in the agriculture sector was greatly influenced by COVID-19 due to mobility restrictions. Accessibility to on-farm and off-farm labor was driven by lack of finances, inability to hire, and/or increased reliance on household members for labor. The industrial work stoppage forced urban labor to migrate to rural areas. Nonetheless, survey results indicate that 75.5% of respondents experienced reduction in access to labor due to a lack of finances during the 2020 growing season. Job losses in off-farm activities imposed financial strain on rural households, which led to a reduction in the accessibility of labor. About 60.6% of respondents experienced reduced access to labor due to a lack of individuals to hire, and 75.6% of respondents reported increased reliance on household labor during the pandemic. The savings crunch, credit limitations, and disrupted markets accompanied by the social stigma of the pandemic, forced individuals to not hire labor on their farms and rely on household members for on-farm and off-farm activities. These percentages are the aggregation of the two response categories "somewhat agree" and "strongly agree." (Table 7).

Table 7. Thinking about your experience of what has occurred due to COVID-19, please indicate your agreement or disagreement with the following statements related to access to labor.

Statement	Strongly Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree	Total	Mean (SD)
Reduced access to labor due to a lack of *finances* during this season	85 (9.8%)	64 (7.4%)	63 (7.3%)	236 (27.2%)	418 (48.3%)	866	3.96 (1.31)
Reduced access to labor due to a lack of *individuals to hire* during this season.	161 (18.6%)	88 (10.1%)	92 (10.6%)	214 (24.7%)	311 (35.9%)	866	3.49 (1.51)
Increased reliance on *household labor* during this season.	52 (6.0%)	36 (4.2%)	123 (14.2%)	185 (21.4%)	470 (54.2%)	866	4.14 (1.17)

Note: Means are on a 5-point scale (1 = Strongly Disagree to 5 = Strongly Agree).

Table 8. If depending on off-farm labor, please indicate the level of access to labor throughout the agricultural cycle.

Off-Farm Labor Accessibility	Frequency (n = 866) (%)
Much less	180 (20.8)
Somewhat less	221 (25.5)
About the same	77 (8.9)
Somewhat more	35 (4.0)
Much more	14 (1.6)
I do not depend on off-farm labor	339 (39.1)

If farmers depended on off-farm labor, they were asked additional questions related to the access to labor throughout the agricultural cycle and the ability to hire workers from within and outside their communities. In response to these questions, 39.1% of farmers indicated that they do not depend on off-farm labor. The responses are summarized in Table 8. Almost 60% of respondents indicated some scale of reduction in accessibility to off-farm labor throughout the agricultural cycle. Health care was a major concern for off-farm labor accessibility. The International Labor Organization [43] estimated that globally ~1.6 billion informal workers (76% of informal employment) were impacted by pandemic related restrictions, and African countries were expected to have more job loss and labor issues in the informal sector [43]. They also forecasted that until the end of 2022, the younger workforce would continue to face these issues as developing countries like Senegal struggle to stimulate economic recovery.

The head of household hires off-farm workers in rural Senegal mainly from their community, the region, or from neighboring countries. Due to border closures, labor movement from other countries was restricted. Getting labor from the local community was more difficult due to mobility restrictions and health concerns of the laborers. Respondents were asked to select multiple options for the source of off-farm labor. As illustrated in Figure 7, 53.5% of respondents were able to hire workers from their community, 37.4% from their region, and 4.2% from other countries. The survey indicates that 67.9% of respondents experienced a reduction in labor accessibility (Figure 8). Specifically, they were asked if they were able to hire labor for planting and harvesting during the agricultural cycle, and 48.8% respondents faced problems in hiring laborers. Most of them managed through family members (women and children).

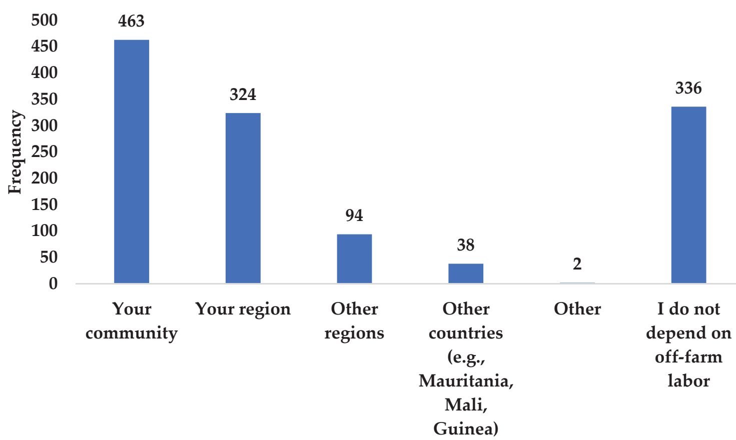

Figure 7. Ability to hire off-farm labor (n = 866).

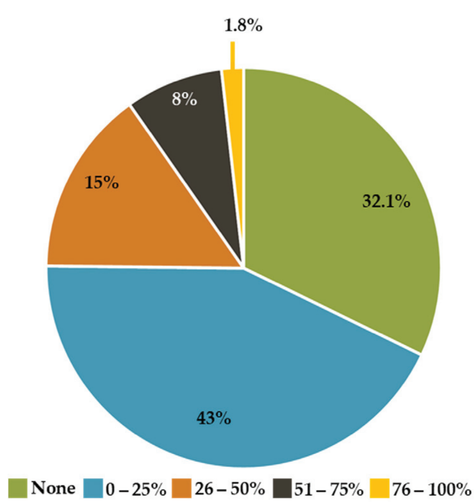

Figure 8. Reduction in labor accessibility.

3.3.3. Impact on Gender Equity

Gender disparity is a global phenomenon in the agricultural sector of developing countries, where women face resource constraints, contested ownership, and often a lack of decision-making power. These constraints can be alleviated by active participation in decision-making. In Senegal, women usually do household activities (e.g., family care, nutrition, marketing), take care of poultry and milking animals, and help in planting and harvesting during the growing season. Due to the pandemic, women farmers faced challenges in active participation in decision-making, allocation of farm resources, and lack of access to technical know-how [44,45]. The survey results illustrate the major impacts of COVID-19 on women. Respondents (83.2%) indicated that there was a significant increase in household activities (e.g., meal preparation, water collection, childcare), primarily due to more household members losing their jobs and staying at home due to mobility restrictions. It also led to an increase in domestic violence against women in Senegal [44]. Respondents (57.1%) indicated that there was a significant decrease in on-farm activities due to the increase in household activities and more family members at home due to curfews and travel restrictions. Regarding challenges for women and issues related to labor, most respondents received help from family members in on-farm activities due to the earnings shortage. However, 56.8% of respondents experienced a significant increase in off-farm activities (Table 9), based on the aggregation of the two response categories "somewhat agree" and "strongly agree".

Table 9. Thinking about what occurred for women due to COVID-19, please indicate your one best response to the following statements . . . .

Statement	Strongly Dis-agree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree	Total	Mean (SD)
There was a significant *increase* in women's labor *in the household* (e.g., meal preparation, water collection, childcare, etc.).	43 (5.0%)	51 (5.9%)	51 (5.9%)	246 (28.4%)	475 (54.8%)	866	4.22 (1.11)
There was a significant *decrease* in women's labor in *on-farm activities* (e.g., planting, weeding, irrigating, harvesting, etc.).	115 (13.3%)	166 (19.2%)	90 (10.4%)	218 (25.1%)	277 (32.0%)	866	3.43 (1.43)
There was a significant *increase* in women's labor *in off-farm activities* (e.g., wage labor, market activities, etc.).	118 (13.6%)	134 (15.5%)	122 (14.1%)	156 (18.0%)	336 (38.8%)	866	3.52 (1.46)

Note: Means are on a 5-point scale (1 = Strongly Disagree to 5 = Strongly Agree).

Respondents were also asked to consider the multifaceted impacts of the pandemic on women. Women faced challenges in three aspects: (1) physical burden to support the head of household, (2) financial risk in view of low product sales, and (3) mental anxiety for children and dependents in the family. During the peak of COVID-19, women's responsibilities multiplied. The key challenge was to support the head of household, which includes working on both the farm as well as in the home. This led to an overload in women's daily activities as they had to work throughout the day, leading to physical stress. Further, because of the closure of local markets, sometimes they had to travel to distant markets to sell dairy and other agricultural products in addition to taking care of livestock at home. Due to the lockdown, women faced individual-level health resilience issues due to reduced access to health care with confinement. Along with physical stress, they also experienced financial burden due to the poor sale of agricultural products. Moreover, because of low-income flow, other women's activities in terms of petty trading were suspended. They were also affected mentally due to concerns for child nutrition, their education, and the well-being of other dependents of the household.

3.3.4. Impact on Youth

Africa has youngest population in the world; however, two-thirds of the youthful population are either unemployed or forced into low wage jobs. Agriculture, which contributes more than 17% to Senegal's GDP, has untapped potential for youth employment.

The pandemic has damaged agricultural systems by severely impacting supply chains. The persisting challenges of lack of financial support, land ownership, and technical training prevent youth from engaging in farming activities [46]. This trend improved during the pandemic, as many young farmers lost their off-farm jobs and focused on on-farm jobs [47]. The survey indicated that 62.7% of respondents experienced a significant increase in on-farm activities, while only 36.7% experienced significant increase in off-farm activities. These percentages are the aggregation of the two response categories "somewhat agree" and "strongly agree." (Table 10).

Table 10. Thinking about what occurred for youth due to COVID-19, please indicate your one best response to the following statements.

Statement	Strongly Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree	Total	Mean (SD)
There was a significant *increase* in local youth's labor with *on-farm* activities (e.g., weeding, planting).	80 (9.2%)	156 (18.0%)	87 (10.0%)	216 (25.0%)	327 (37.7%)	866	3.64 (1.37)
There was a significant *increase* in local youth's labor with *off-farm* activities (e.g., wage labor, market activities).	206 (23.8%)	186 (21.5%)	156 (18.0%)	136 (15.7%)	182 (21.0%)	866	2.88 (1.46)

Note: Means are on a 5-point scale (1 = Strongly Disagree to 5 = Strongly Agree).

The survey also asked open-ended questions about the greatest challenges that COVID-19 posed for youth in their households and community. The pandemic impacted the lives of youth in a multitude of ways. The top challenges included: (i) unemployment, (ii) cessation of agricultural and production activities, (iii) lack of access to resources necessary for survival, and (iv) reduction in purchasing power. While there were young people who returned to villages and confined themselves, some emigrated to find work, legally or illegally. Owing to unemployment, travel restrictions and a lack of other resources, a significant proportion of youth was stranded in villages and tried consistently to move to urban areas of Europe in search of income-generating activities. Youth who used to work in fields were looking for jobs in the factories, industries, or completely new areas to ensure some source of income which would help them satisfy their basic needs. There was a strong initiation of young people into production activities and the management sector. Some respondents lacked access to the internet, difficulty in accessing Wi-Fi hotspots, a lack of digital access to take online courses and weak computing infrastructure. Overall, youth in Senegal were striving to participate in the holistic development of the community, seek employment, provide for their own needs and search for alternative sources of income.

3.4. Short Term Resiliency in Adapting to COVID Related Shocks

3.4.1. Change in Cropping System, Practices, and Calendar

Senegal relies heavily on the import of agro-chemicals and hence is vulnerable to the socioeconomic impacts of the pandemic due to supply chain problems. With growing data on evaluating the impacts, robust policy can be designed. To date researchers have designed sporadic and patchwork plans without any long-term resilient mechanisms. However, based on resource availability, growers have adapted their crop plans and associated decisions on-farm and off-farm. Hence, the survey explored household experiences and in-season adjustments in their crop types, practices, and calendar. Latané et al. [21] highlighted that rural households were worried that their food stock would run out if they did not receive food aid from the government or other agencies. Thus, they used most of their credits in planning to grow enough food on time. Ninety five percent of respondents did not change crop type, practices, or the cropping calendar. However, of 5% who changed their crop type, 60% of them shifted to vegetables to diversify their farm and 40% shifted to less perishable alternative of cereal crops. In practice, they shifted to fast-growing vegetables and applied organic manure instead of synthetic fertilizer, and this might be attributed to the closure of markets and unavailability of fertilizers. They also faced labor shortages;

hence, field preparation jobs were performed by household members. They shifted to short duration crops and thus modified the planting and harvesting calendar.

Respondents were also asked to share their relationship with the farmers organizations. Their membership in different organizations helped them in coping strategies such as utilization of social capital, resource allocation, and additional well-being support for strengthening household-level and community-level resilience capacity [21]. A large majority (82%) of respondents indicated having a strong relationship with farmers organizations, and 53% of these considered themselves frequently involved with their organizations (Table 11).

Table 11. Involvement with farmer organization.

Frequency of Engagement	Frequency (n = 804) (%)
Always	168 (20.9)
Most of the time	258 (32.1)
About half the time	81 (10.0)
Sometimes	193 (24.0)
Never	102 (13.0)

The data indicated that 75.5% of respondents experienced significant disruptions in extension and advisory services, while 74.1, 51.7, and 50.1% faced communication barriers through organization, phone, and radio/television, respectively, during the pandemic. These percentages are the aggregation of the two response categories "somewhat agree" and "strongly agree" (Table 12). Farmer's extension services helped in the timely dissemination of knowledge and services related to weather advisories. However, due to mobility restrictions, most of the information related to animal disease monitoring and chemical applications on crops was not delivered to growers. Crop yield losses might be attributed to these factors. With a diverse agriculture sector, extension through telecommunication is not a one-size-fits-all delivery of information. These barriers were overcome by some farmers' groups who managed extension services well in different parts of Senegal [21].

Table 12. Thinking about what occurred due to COVID-19, please indicate your level of agreement for each of the following statements.

Statement	Strongly Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree	Total	Mean (SD)
There were significant disruptions in *extension and advisory* services for farmers.	22 (2.7%)	56 (7.0%)	119 (14.8%)	161 (20.1%)	444 (55.4%)	802	4.18 (1.09)
There were significant disruptions in *communication* from farming organizations/networks	26 (3.2%)	69 (8.6%)	113 (14.1%)	167 (20.8%)	427 (53.3%)	802	4.12 (1.13)
There were significant disruptions in *receiving information* via cell phone	128 (16.0%)	120 (15.0%)	139 (17.3%)	146 (18.2%)	269 (33.5%)	802	3.38 (1.47)
There were significant disruptions in *receiving information* via radio and/or television.	112 (14.0%)	140 (17.5%)	148 (18.4%)	125 (15.6%)	277 (34.5%)	802	3.39 (1.45)

Note: Means are on a 5-point scale (1 = Strongly Disagree to 5 = Strongly Agree).

3.4.2. Livelihood and Social Well-Being Interventions

During the pandemic, food stocks in the household, and receiving food aid, were two major concerns among respondents regarding food security. On average, cereal stock in Senegal is ~8 kg/month/person as of 2017 [21]. The survey results indicate that 85.9% of respondents experienced difficulty in getting enough food for their household on a regular basis. The closure of local markets to buy and sell produce, can create price volatility and inflation. About 92.9% and 89.6% of respondents experienced local closures of markets where they purchase and sell produce respectively, and 79.1% faced price increases due to market disruptions. These percentages are the aggregation of the two response categories "somewhat agree" and "strongly agree" (Table 13).

Table 13. Thinking about what occurred due to COVID-19, please indicate your one best response to the following statements.

Statement	Strongly Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree	Total	Mean (SD)
Getting *enough food* on a regular basis for my household became more difficult	17 (2.0%)	39 (4.5%)	66 (7.6%)	213 (24.6%)	531 (61.3%)	866	4.39 (0.94)
The market where I purchase food for my household was either *closed or significantly* disrupted	16 (1.8%)	11 (1.3%)	34 (3.9%)	214 (24.7%)	591 (68.2%)	866	4.56 (0.78)
There was a significant increase in the *price of foods* that I purchased for my household	15 (1.7%)	41 (4.7%)	124 (14.3%)	205 (23.6%)	481 (55.5%)	866	4.27 (0.98)
The market where I sell the produce/ livestock from my farm was either *closed or significantly* disrupted.	13 (1.5%)	10 (1.2%)	67 (7.7%)	203 (23.4%)	573 (66.2%)	866	4.52 (0.82)

Note: Means are on a 5-point scale (1 = Strongly Disagree to 5 = Strongly Agree).

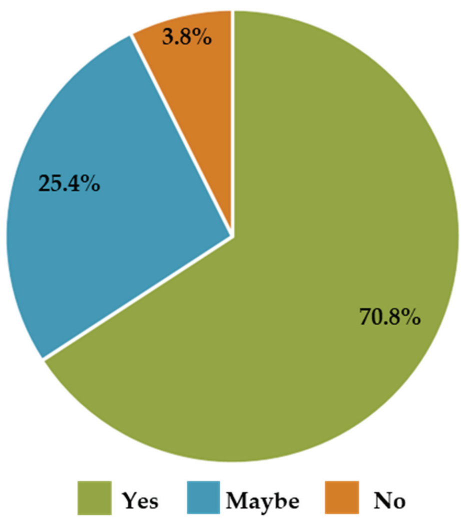

Figure 9. Impact of COVID-19 on the following agricultural season.

Table 14. Thinking about your experiences of what occurred due to COVID-19, please indicate your level of agreement for each of the following statements.

Statement	Strongly Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree	Total	Mean (SD)
I did not have access to *other social services* to help my household	414 (47.8%)	163 (18.8%)	36 (4.2%)	66 (7.6%)	187 (21.6%)	866	2.36 (1.62)
I did not have access to *farm credit*	413 (47.7%)	159 (18.3%)	49 (5.7%)	55 (6.3%)	190 (22.0%)	866	2.36 (1.62)
I did not have access to *subsidies*	439 (50.7%)	101 (11.7%)	28 (3.2%)	89 (10.3%)	209 (24.1%)	866	2.45 (1.70)
I did not have access to other *financial supports*	563 (65.0%)	146 (16.9%)	52 (6.0%)	24 (2.8%)	81 (9.3%)	866	1.75 (1.26)

Note: Means are on a 5-point scale (1 = Strongly Disagree to 5 = Strongly Agree).

Amidst growing food insecurity, market disruptions, and price volatility, respondents were asked if they expect to face any consequences in the next agricultural season; 70.8% said “Yes,” and 25.4% said, “Maybe” (Figure 9). This indicates uncertainty among respondents regarding ongoing economic impacts of COVID-19 on next year’s agricultural cycle. Robust policy support could curtail these uncertainties and vulnerabilities. Interestingly, the results indicated that 66.6% of respondents had access to other social services to help their household, 66% had access to farm credits, 62.4% had access to subsidies, and

81.9% had access to other financial supports. These percentages are the aggregation of the two response categories "somewhat disagree" and "strongly disagree." (Table 14).

For smallholder farmers, financing is primarily used for agricultural production (e.g., purchase of inputs, labor), and thus is a critical form of support. In light of the disruptions of the pandemic respondents considered calibrating their plans for the next agricultural year. For example, 69.6% of respondents planned to make changes in their agricultural practices next year, 67% respondents would diversify crops next season to balance between food security and financial security by focusing more on exporting high value cash crops, 77% of respondents said they would take precautions against future disruptions in terms of finances and resources associated to on-farm and off-farm activities, and 76% of respondents said they would engage more with service organizations for support for finance and farm advice. Latané et al. [21] highlighted the role of farmers' networks and organizations in short term resiliency of households against COVID-19 in Senegal, especially in providing accessibility to inputs and financing. These percentages are the aggregation of the two response categories "somewhat agree" and "strongly agree." (Table 15).

Table 15. Thinking about your experience of what has occurred due to COVID-19, please indicate your agreement or disagreement with the following statements related to what you would do differently for the next agricultural cycle if anything.

Statement	Strongly Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree	Total	Mean (SD)
I would make *some changes* to my agricultural practices	108 (14.0%)	31 (4.0%)	95 (12.3%)	185 (24.1%)	350 (45.5%)	769	3.83 (1.40)
I would *increase* the *diversity* of crops; I plant and produce	122 (15.8%)	35 (4.6%)	97 (12.6%)	223 (29.0%)	292 (38.0%)	769	3.69 (1.42)
I would *increase* my *precautions* against future disruptions in terms of finances and resources (e.g., on-farm and off-farm activities)	38 (5.0%)	31 (4.0%)	108 (14.0%)	200 (26.0%)	392 (51.0%)	769	4.14 (1.11)
I would engage *more with service organizations* for support (e.g., farmers, financial, advisory)	35 (4.6%)	25 (3.3%)	124 (16.1%)	158 (20.5%)	427 (55.5%)	769	4.19 (1.10)

Note: Means are on a 5-point scale (1 = Strongly Disagree to 5 = Strongly Agree).

3.4.3. Policy Support

The impact of COVID-19 on farming systems varies geographically with multiple dimensions, and hence, one uniform policy cannot fit all cases. The microeconomic impact on smallholder farmers can be eased by food aid and family support such as on-farm labor. However, high cash value export-oriented crops were more exposed to international trade disruption, supply, and finance shocks. As current and post-pandemic economic recovery progresses, short-term and long-term policy measures for resilient systems are needed, including investment mobilization to minimize the financial gap. The major short-term policy support in Senegal was to strengthen small and medium enterprises to provide off-farm jobs to households who were laid off due to disruptions. The associated debt finance, employment support, tax, and business advice offered transient financial stability [10]. To minimize the impact of the pandemic on household nutrition, the Ministry of Agriculture and Rural Equipment (MAER), together with global development agencies, started the "Housewives' Basket" initiative in Senegal. The Senegalese government has also revised the second phase of Senegal Emergent Plan to steer funding towards the promotion of intensive and resilient farming systems.

The FAO has launched the "Household Food Basket" initiative using its anticipatory action fund in Senegal to strengthen the resilience of smallholder farming systems and to protect food supply chains [11]. It created a digital platform where small entrepreneurs can engage in trade, which boosted women food processors and local economies along with efforts on food aid focused on child nutrition [12]. The World Bank's International Development Association (IDA) supported Senegal with USD 150 million credit to strengthen and build resilient agricultural systems [9]. World Food Program (WFP), through the R4 Rural Resilience Initiative, helped hundreds of households in building resilient food systems through weather insurance and the creation, with smallholder farmers, of village cereal banks for meal plans for school kids [13]. To mitigate the impact of COVID-19, the International Fund for Agricultural Development (IFAD) in coordination with the FAO, WFP, and the Green Climate Fund (GCF) revitalized economic activities for Senegal [14]. Peace Corps Senegal, in collaboration with the USAID Feed the Future program, supported the Master Farmers program during the pandemic via its sustainable rural agriculture extension agents' network.

4. Conclusions

The COVID-19 pandemic disrupted markets, supply chains, and labor availability, which severely impacted smallholder farming systems in Senegal. The main objectives of this study were to explore the actual experiences of smallholder farmers in Senegal with COVID-19, how those experiences impacted their systems, and how farmers developed short-term adaptive capacities. The survey results indicated that the major impacts of the pandemic on smallholder farmers more likely came from disrupted supply chains and mobility restrictions. However, we also recognize that there were other subtle and indirect impacts on smallholder farming systems. Given the connecting links between the pandemic and its multifaceted drivers, we concluded that a detailed quantitative and qualitative assessment of the impacts was needed to capture the impacts of the pandemic on smallholder farming systems. This survey helped us to identify risk factors, gauge the adaptive capacity of rural households and enumerate the initiatives and policy support to strengthen resilience of farming systems.

The survey results captured the experiences of respondents during the pandemic and indicate a need to address these concerns to mitigate the impacts of future shocks. However, as with any research, there are some limitations to this study. First, because the survey was conducted by cellphone, those smallholders without cellphones could not be reached. Further, the sample is majority male, thus the experiences and perceptions of women are somewhat underrepresented in this data. Finally, this study was considered an initial baseline. Follow-up research would include more formal analyses, as well as in-depth interviews with a subset of respondents to further verify the data.

The biophysical (crops and livestock) and socioeconomic (labor, market, gender, and well-being) impacts on farming systems during the pandemic call for significant concerns about the precariousness of the situation, as well as concerns with policy planning. Further research on the short-term and long-term impacts on rural livelihoods as well as policy implications is warranted. This study will assist researchers in measuring the vulnerability of households to shocks and mitigate the impacts for improved and resilient smallholder farming systems. The baseline survey obtained from this study will be valuable to policymakers and other stakeholders to design mitigation strategies for resilient smallholder farming systems.

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Article

Feasibility Study of a Small-Scale Recirculating Aquaculture System for Sustainable (Peri-)Urban Farming in Sub-Saharan Africa: A Nigerian Perspective

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Abstract: The (peri-)urban population in developing countries, especially sub-Saharan Africa, is rapidly increasing. As towns and cities grow, so does the demand for fish protein. While flow-through aquaculture can provide fresh, healthy and nutritious fish protein, it is plagued by extensive land requirements as well as effluent discharge and is thus unsuitable for city regions. Alternatively, small-scale Recirculating Aquaculture Systems (RAS) could improve food and nutritional security and livelihoods as well as reduce environmental degradation in (peri-)urban areas despite land and water constraints. The question, however, remains—what are the key technical, business and managerial issues surrounding small-scale RAS in (peri-)urban farming? To answer this question, first, a systematic literature review on RAS in sub-Saharan Africa is conducted. Second, the RAS prototype of the Sustainable Aquaponics for Nutritional and Food Security in Urban Sub-Saharan Africa (SANFU) II project is assessed. This assessment is based on the mass balance and stock density, relevant for fish survival and/or availability as well as net cash flow analyses. The results suggest that small-scale RAS are technically and financially viable with efficient filtration and family labor having proper aquaculture monitoring and management skills. Furthermore, access to adequate equipment and inputs as well as electricity for the recirculating system are crucial. (Peri-)urban innovation actors will adopt RAS if operations are profitable.

Keywords: food security; (peri-)urban farming; fish protein; RAS; land; water; Nigeria; sub-Sahara Africa

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1. Introduction

The increasing population and urbanization in sub-Saharan Africa is reaching unprecedented levels. In a number of instances, urbanization has passed the 50% threshold [1]. A number of factors ranging from high fertility rates to rural–urban migration drives population growth and urbanization [2,3]. This implies that there will be a substantial increase in the demand for animal-sourced foods (ASF), specifically fish protein, in cities and towns, which today's (rural) producers will be unable to meet [4]. Furthermore, prospective (rural) fish farmers, often young and agile, seek greener pastures in cities abandoning farming altogether. This exacerbates the fish supply deficit observed in sub-Saharan Africa, particularly in Nigeria, where the fish consumption rate is less than 10 kg compared to the world average of 19 kg per person per year [5]. This is more severe among women and children, resulting in malnutrition and one of the highest stunting rates among children under the age of five [6]. To compensate for this deficit, (peri-)urban vulnerable groups often turn to backyard gardens and other micro- and small-scale agribusinesses for subsistence as well as income generation [7]. Thus, one of the alternatives and viable options for ensuring food and nutrition security (FNS) and alleviating poverty in (peri-)urban areas that has gained recognition over the years is (peri-)urban farming. The term (peri-)urban farming implies the cultivation of plants and the raising of animals for food in cities and towns (similar to the definition of urban agriculture by De Bon et al. [8]). Urban and peri-urban farming has to be embedded in urban planning and development as well as urban–rural interactions given its demand for scarce resources such as land as well as the corresponding water, energy, food and ecosystem resources, the so-called WEFE Nexus.

Conventional (peri-)urban farming related to (flow-through) aquaculture has always been relevant for animal protein in and around cities and towns in developing countries, specifically, Lagos, Nigeria [2]. However, flow-through aquaculture involves the consistent exchange of fish wastewater for maintaining water quality levels and fish health. This leads to a high discharge of effluents (effluent is any form of liquid waste that is discharged into a body of water) into the ground water as well as other water bodies, resulting in eutrophication (eutrophication is the prevalence of excessive nutrients in a body of water). The increasing rate of urbanization, particularly in sub-Saharan Africa, raises questions about the ability of flow-through aquaculture to be viable given land and water constraints as well as environmental concerns. Climate change introduces additional challenges to flow-through aquaculture as the competition for water and ecosystem services intensifies and non-circular food systems heighten the strained relationships between the WEFE Nexus. However, limited efforts in improving productivity and efficiency while reducing environmental pollution in conventional aquaculture in African cities have been made [9–13]. The ongoing COVID-19 pandemic, and more recently the Russian–Ukrainian conflict, have further aggravated the food and nutrition insecurity of (peri-)urban dwellers in sub-Saharan Africa [14]. Both external shocks disrupted regional and international supply and value chains and caused food and energy price inflation. This experience revealed the need to make local and regional food systems more crises-proof, which means increasing system resilience while conserving resources and the environment.

Thus, to improve (peri-)urban FNS and to reduce the pressure on the environment, Davies et al. [9] and FAO [15] call for the introduction of novel circular agri-food technologies and practices in the (peri-)urban food systems, which simultaneously generate income through profitable businesses. A number of studies [4,16–18] have also emphasized the need for innovative (peri-)urban farming technologies that require limited resources (i.e., land and water). Examples of such innovations include recirculating aquaculture systems (RAS). These technologies are suitable for African (peri-)urban settings because they do not require great access to land, water or wealth. Moreover, they can spur job creation, especially for women and young adults. According to Fornshell and Hinshaw [11] (p. 11), "recirculating aquaculture systems consist of a culture unit connected to a set of water treatment units that allows some of the water leaving the culture unit to be reconditioned and reused in the same culture unit. Recirculating aquaculture systems minimally require water treatment processes to remove solids, remove or transform nitrogenous wastes, and add oxygen to the water". However, the rather high up-front costs of RAS and the operating costs related to electricity, which is essential to maintain the water circulation and aeration, have limited its adoption among (peri-)urban farmers [11]. Furthermore, Ahmed and Turchini [19] and Bodiola et al. [20] argue that the rather complex fish production technology limits the adoption and implementation of RAS in developing countries, especially in those of sub-Saharan Africa. Bodiola et al. [20] also attribute the lack of skilled staff for water quality control and repair of mechanical faults to the slow adoption of RAS. Despite all its advantages with regard to improving FNS as well as the WEFE Nexus, the relatively high up-front costs and the related delay in the payback period may discourage poor and vulnerable (peri-)urban dwellers to adopt RAS. Nevertheless, Aich et al. [21] argue that RAS has the potential to produce 30–50 times more fish per unit area compared to conventional fish farming. However, the economic viability of relevant parameters such as optimal and maximum density, market prices, energy cost, etc., are often based on best guesses. This implies that data, which provide insights on the challenges and opportunities of (peri-)urban RAS adoption and implementation, are lacking. Thus, RAS has not witnessed broad adoption and implementation in (peri-)urban farming in developing countries, especially in sub-Saharan Africa [16–21].

This leads to the research question: what are the key opportunities and challenges of small-scale RAS implementation in (peri-)urban farming contexts from a technical, business and managerial perspective in sub-Saharan Africa?

To answer this research question, this study first conducts a systematic literature review of RAS, and secondly, revisits the design and technical details as well as costs and benefits of micro- and small-scale RAS in Africa. We explore the results for one fish production cycle of the Sustainable Aquaponics for Nutritional and Food Security in Urban Sub-Saharan Africa II (SANFU II) project from March to June 2022. The SANFU II RAS prototype is a simple micro- and small-scale RAS (600-L fish tank, sorting and sump tanks with 148 African Catfish—*Clarias Garipinus*) undergoing testing in Lagos, Nigeria. The design, capacity and cost related to setting up and managing the SANFU II RAS are presented.

In a nutshell, the results suggest that micro-and small-scale RAS can be stocked at a density that is higher than conservative recommendations given an efficient filtration system is in place. This relative high stocking density requires certain management skills and entails a higher risk of fish mortality. The monthly fixed and variable costs associated with running the RAS for a complete fish production cycle of four months were estimated at ₦36,733 (US$63) and ₦16,733 (US$29), respectively, and can be reduced if managed by skilled family members. Unemployment rates in developing countries in sub-Saharan Africa are rather high: the unemployment rate in Nigeria reached 33%, the youth unemployment rate, 42.5% (2021 and 2022, www.statista.com/statistics, accessed on 18 October 2022). This does not account for those people who might want to work but are not actively searching for employment. They are classified as discouraged job seekers or as hidden unemployed. Both forms of unemployment reflect an important loss of productive capacity, loss of national income, and issues of social exclusion [22]. Thus, smallholder farming in (peri-)urban areas can bring the unemployed family members back into the productive production process. While their labor may not be paid according to their marginal productivity if employed in the so-called first labor market, they are paid according to the average productivity of all family members as they raise the overall (subsistence and cash) family income.

The paper is structured as follows: Section 2 presents the materials and methods used. A systematic literature review is summarized in Section 2.1 and the technology and business management analysis of small-scale RAS in (peri-)urban farming is outlined in Section 2.2. Section 3 presents the results of the analysis. Section 4 provides insightful discussion of the results before concluding in Section 5.

2. Materials and Methods

2.1. Literature Review—RAS Performance, Opportunities and Challenges in Africa

Different forms of aquaculture have existed for centuries. Nevertheless, conventional flow-through aquaculture relies on abundant supplies of water and land and contributes to the generation of greenhouse gas emissions and loss of biodiversity. RAS expands the frontiers of current food production practices, especially with regard to reducing the pressure on the WEFE Nexus. Yet, while RAS has gained traction worldwide, its adoption and implementation rate is still rather modest on the African continent. Therefore, the key technical, business and managerial issues surrounding RAS in Africa are explored in the following based on a systematic literature review.

The following electronic academic databases were consulted in October 2022 for relevant articles on the subject matter: Google Scholar, Scopus, PubMed, ISI Web of Science, ResearchGate and ScienceDirect, similar to the studies by Houessou et al. [23] and Guo et al. [24]. The following keywords and descriptors were used as search criteria, namely: recirculating aquaculture system, RAS, performance, profitability, challenges, opportunities, urban farming, food security, poverty alleviation and Africa. This exercise also includes assessing the reference lists of the identified articles to ensure that relevant studies were included. The result from the database search with all keywords produced 104 citations, of which 84 were from Google Scholar and a total of 20 citations were from all other aforementioned databases. Once the literature search was complete, these 104 titles were screened for applicable papers using specific inclusion and exclusion criteria. The inclusion criteria include the continental focus, i.e., Africa, concrete estimates of RAS performance in terms of quantity, e.g., kg/m^3 or g/fish, profitability in monetary terms and case studies. The exclusion criteria range from non-social-science and engineering studies to those studies conducted outside Africa. See Figure 1 for the selection process steps for relevant articles. The identification process of references, screening and eligibility criteria methodology followed Guo et al. [24].

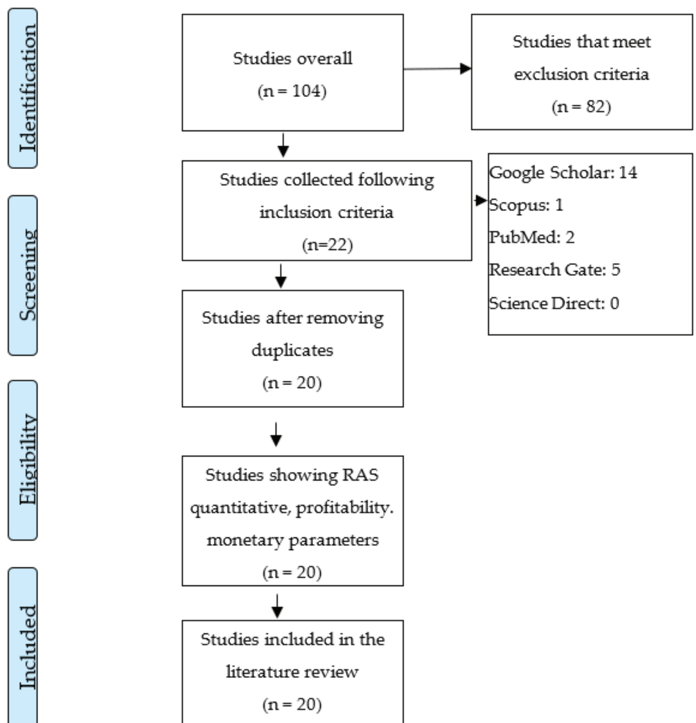

Figure 1. Flow diagram of literature review. *Source: Authors*.

The systematic literature review reveals that RAS is not widespread across African countries (except for South Africa and Kenya). This may explain why documentation of production processes and data are sparse [25–27]. This impression is further evidenced by the rather small number of 20 studies from the systemic literature review. Some of the African countries that have implemented RAS include Kenya, Namibia, Nigeria and South Africa, mostly for Tilapia and to some extent African Catfish [28]. The pilot project of the use of solar-powered RAS in Tilapia hatchery in Kisumu, Kenya, in 2020 resulted in the collection of 19,500 eggs from a total of 560 Nile Tilapia after 5 days valued at KSH50,000 (US$470) [29]. Munguti et al. [30] argue that RAS is efficient in reducing the grow-out period for Tilipia in Kenya, which reaches table size weight of 400–500 g within 4 to 5 months as compared to 300 g in 9 months based on conventional aquaculture. The intensive fish farms in Kenya, which use RAS for hatchery to the grow-out phase, had stocking densities of up to 125 kg/m^3 and an annual production of up to 200 tons in

2020 [28,30–33]. The use of RAS in Kenya is argued to require limited space, conserve water, lower feed costs by up to 50% and increase survival rates up to 25% due to water quality control compared to conventional aquaculture systems [28,34]. Wambua et al. [35] found that for RAS in Kenya, low stocking densities (2.3 kg/m^3 to 5.0 kg/m^3) resulted in longer payback periods compared to higher stocking densities between 7.0 kg/m^3 to 10.0 kg/m^3. Wambua et al. [36] argue that the performance of RAS with respect to high water quality, increased production and profitability can be improved if adequate skills on stocking biomass, power and water flow rate are made available to farmers in Kenya. In Nigeria, Akinwole and Faturoti [37] found that the high RAS stocking density of 176.6 kg/m^3 was possible for African Catfish due to their hardy nature, but cautioned on the prevalence of poor water quality, low growth rate and extended culture duration. Similarly, Atse et al. [38] found that for the Ivory Coast, the survival rate and biomass of African Catfish increase as the stocking density increases, but at the expense of the fish growth rate. Soliman and Yacout [39] argue that RAS is a good alternative to the conventional aquaculture systems found in Egypt, e.g., cages, earthen and concrete ponds. In comparison to conventional aquaculture in Egypt, RAS only requires 20% of the water and minimal land [39]. RAS production cycle trials in Egypt in 2010 resulted in 18.9 tons of fish with a total cost of E£ 141,368 (US$25,106) and was reported to be economically viable [40]. However, in the case of a stocking density of 250 g/fish in Tilapia RAS production in Egypt, seed or fry (small fishes) costs represented 56% of the variable costs, which is approximately seven times that of conventional production [41]. In Ghana, the use of RAS is slowly gaining traction since its introduction some eight years ago with over 150 aquapreneurs across the country using some form of a recirculating tank culture system [42]. According to Amponsah and Guilherme [42], RAS units in Ghana have the capacity of 400 Tilapia fingerlings or 1000 Catfish fingerlings (approx. at 10 g) for a table size of 300 g and 1 kg, respectively, in a span of 4–6 months. The business case study for a large-scale hatchery and grow-out with a capacity for 50 million fingerlings in Ghana in 2015 found that an annual net profit of US$1.1 million is achievable [43]. In Mmadinare, Bostwana, a large-scale RAS system was built to produce more than 500,000 fingerlings but is currently not functioning at capacity [44]. The analysis of specific farms using RAS in South Africa by Oyeleke [45] suggests that the gross profit ranges between R33,334 (US$1822) and R840,000 (US$ 45,900) for a production cycle.

To summarize, the major advantages of RAS for African countries comprise the high stocking density, often more than 100 fish per m^3, thus requiring considerably less water and land per kilogram of fish produced. Furthermore, operation in a controlled environment reduces losses through predators and theft [46]. However, the financial viability of small-scale RAS business models needs to be verified in the absence of subsidies [34].

According to Kaleem and Sabi [47], the major challenges for aquaculture development in Africa, which also restricts the adoption and implementation of RAS, are an inadequate supply and high cost of inputs, poor management practices, high capital and operational costs and lack of appropriate innovations. In southern Africa, inappropriate production systems, low profitability and a lack inputs were identified as the key factors for not adopting RAS for fish production [44]. According to Fornshell and Hinshaw [11], constant and stable electricity is essential for operating and managing RAS, irrespective of location. Thus, electricity is one of the major challenges foreseen for the implementation of RAS in Nigeria and throughout Africa [16]. Bodiola et al. [20] also identified power failure as a one of the major setbacks for RAS development across the globe. The lack of adequate RAS input supply chains is another major hinderrance in Nigeria [16]. According to Lutz [48], the use of non-standardized inputs can make quality control more difficult, reducing yields and thus profits. Thus, micro- and small-scale RAS tend not to thrive in (peri-)urban areas in Africa if input suppliers are not in close proximity, lack access to quality products and are unreliable.

2.2. RAS Technology—A Technical Overview

Compared to flow-through aquaculture, RAS is a more complex method of fish farming. RAS can be divided into several smaller sections or unit (treatment) processes that work as stand-alone unit or that are linked through a process stream. The basic concept of RAS is to have a solution (i.e., technology) and management in place for the envisaged scaled-up fish production that is effective in the sense of improving the supply of fish protein as well as being profitable within a specific region of the world. The process of a typical RAS (as illustrated in Figure 2) ensures that the water flows from a fish tank and through units that remove solids (settleable, suspended, fine and dissolved), turns the ammonia to nitrate and adds oxygen before the cleansed water is returned back to the fish tank [49]. RAS also requires a monitoring and control system to be in place to avert fish mortality due to poor water quality, diseases and other related risks.

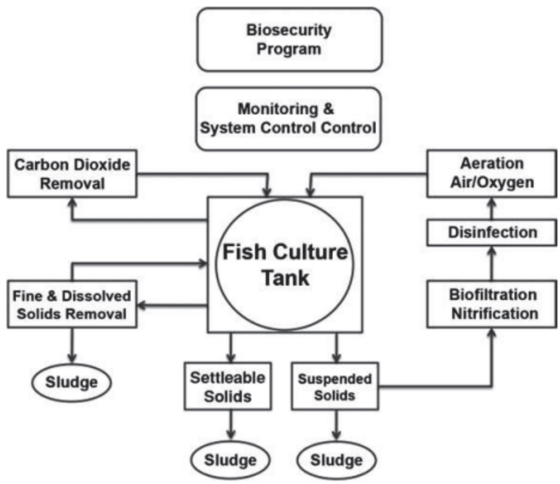

Figure 2. Unit processes used on a recirculating system. *Source: Ebeling and Timmons* [49] (p. 248).

The SANFU II project was implemented on an area of 13.4 m^2 with a partial open greenhouse in Lagos, Nigeria (see Figure 3). Relevant data such as water quality, fish weight, system management, labor input, investment and variable costs (e.g., costs of fish feed) were recorded. Market price information was collected from fish farmers and sellers in and around Lagos as well as through secondary sources. Other relevant data were collected using local knowledge if and when available. The duration of the SANFU II project data collection for this study was from March to June 2022, which corresponds to one production cycle.

The SANFU II project is based on a simplified design and fabrication of RAS consisting of a fish and sump tank, a solid lifting outlet (SLO), a redial flow settler and mechanical and biological filtration that are all linked together as a process stream (see Figure 4). The SLO pushes settleable and suspended solids into the redial flow settler, affixed with a stilling well that ensures settleable solids go to the bottom of the redial flow settler. This redial flow settler is an 80 L barrel. This is different from the Cornell dual-drain system described by Ebeling and Timmons [49] (p. 250), which uses the culture tank itself as a swirl separator ('tea-cup' effect) and removes most of the settleable solids through the center drainage. However, the results are similar in that only minimal water (10 to 25%) is used to displace settleable solids such as leftover feed and fish excrete [49]. Suspended solids are moved to the mechanical filtration system that uses a granular media filter consisting of granite rocks smaller than 1 cm in size as well as fishing nets, which intercept the solids and hinder onward flow. The use of the biological filtration system aids the nitrification process where bacterial activities convert the ammonia to nitrite and then nitrate based on the surface area available for bacterial growth. The media used for surface areas in the biological filtration were the cap of waste plastic bottles (PEP: plastic engineered products) that were cut into four parts to act as floating beads. These floating beads further trap solids that were not intercepted in the mechanical filtration. As stated by Ebeling and Timmons [49] in the case of high levels of stocking density (>45 kg/m^3), similar to that of the SANFU II prototype (148 fishes is equivalent to 74 kg/m^3), an aeration system is needed to provide adequate levels of oxygen. The requirements for monitoring rise with increasing stock density. To this end, the regular measurements of pH and ammonia were conducted through external labor hired to oversee the biosecurity, monitoring and control procedure of the SANFU II RAS prototype. The SANFU II RAS system is equipped with a 3000 L/h water pump and 600 L/h aeration system having a power consumption of 10 Watts per hour (see Figure 5).

Figure 3. Map of Nigeria and location of Lagos State. *Source: Britannica* [50] (p. 1).

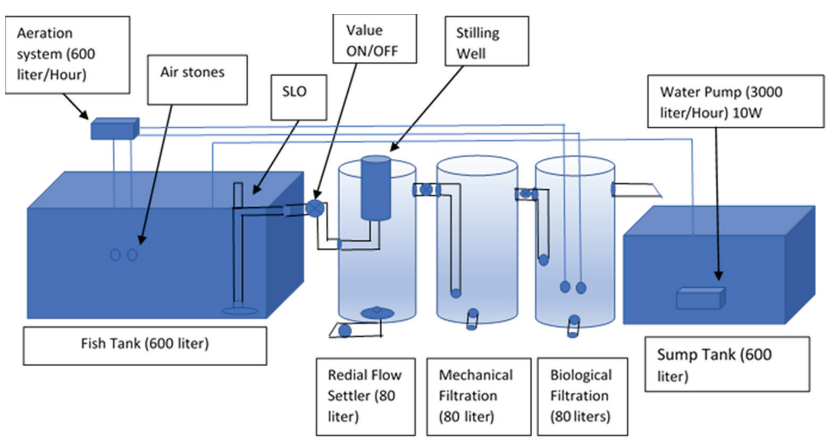

Figure 4. SANFU II micro- and small-scale RAS unit process design. *Notes: SLO = solid lifting outlet. Source: Authors.*

Figure 5. SANFU II RAS prototype implementation. *Source: Authors*.

2.3. Efficiency and Business Management Indicators of RAS

As earlier mentioned, the technical and financial viability of RAS depends on a number of factors ranging from water quality based on filtration, stocking density, monitoring and management of cash flow. Thus, the quality of water will be estimated based on the mass balance, i.e., the volume of solids after filtration, which is also influenced by the stocking density. The mass balance approach makes it possible to track the amount and sustainability characteristics of circular and/or bio-based contents in the parts of the whole of the supply and value chain and attribute it based on verifiable records from the management and monitoring. The cash flow analysis provides business viability estimates.

2.4. Mass Balance

It is important to assess the technical viability of the RAS in developing countries before looking at the cost and benefit implications. Maintaining appropriate and good water quality is essential for the successful management and operations of RAS. The quality of water can be estimated through the mass balance as well as the stocking density calculation [49]. The mass balance is denoted as:

$$Q \times C_{in} + P_{solid} = Q \times C_{out} \tag{1}$$

where C_{in} and C_{out} are concentrations of a vector of variables such as solids in and out of the fish tank (kg/m^3), Q is recirculated water (liters per day) and P_{solid} is the production rate of total suspended solids (TSS) (mg per liter).

P_{solid} can be estimated using the mathematical formula: 0.25 × kg feed fed (dry matter basis (the value of the dry matter basis ranges between 0.20 and 0.40.)).

Solving for C_{out} in kg/L will provide water quality concentration for the filtration device, i.e., leftover particles in a given filter device are estimated using the mass balance analysis and are denoted as:

$$C_{out} = C_{in} + \frac{T}{100}(C_{best} - C_{in}) \tag{2}$$

where $\frac{T}{100}$ is the treatment (T) efficiency (%) of the filter and C_{best} is the optimal result obtainable by the filtration (e.g., no suspended solids).

2.5. Stocking Density

When designing a RAS system, it is important to estimate the number of fishes that can be adequately and safely raised in the anticipated unit volume of the fish tanks. This should be done with the aim of moving the fish to the market once the table size weight, i.e., usually around or above 500 g, is achieved. This pre-defined fish weight of the table size and the number of fishes in the tank are important for determining the feeding rate. Ebeling and Timmons [49] argue that the number of fishes that will be stocked for each unit volume (*density*) is based on the species and size of fish at the grow-out stage. Similarly to the approach of Ebeling and Timmons [49], this study uses the fish body length (*Length*), when the table size weight is achieved, to estimate the number of fishes that can be raised per unit volume of fish tank, denoted as:

$$D_{Density} = \frac{Length}{C_{Density}} \tag{3}$$

where $D_{Density}$ is the total weight of fish that can be stocked (or harvested) per cubic meter measured in kg/m^3, *Length* is the length of fish in cm and $C_{Density}$ is a default value that is dependent on the species of fish (we use a $C_{Density}$ value for the African Catfish of 0.3[4], which is similar to that of trout species). It is, however, important to note that permissible fish stocking densities not only depend on the fish size and technical characteristics of the facility but also on operational and management skills [49].

2.6. System Monitoring and Management

To have a sustainable fish farming development through RAS, it is important to have an adequate management as well as a monitoring system for diseases and pathogens in place [21]. Even the small-scale RAS prototype of SANFU II requires a substantial level of monitoring and correctional measure, especially at a higher stocking density, to guarantee adequate fish wellbeing and yields. The monitoring and management tasks include filtration system cleansing and residual removal, disease control as well as controlled water replenishment. One full-time staff member, a facility manager, with on-site training in aquaculture management, was saddled with this responsibility including data recording, working six hours a day, seven days a week.

2.7. Cash Flow Analysis

Cash flow analysis is used to estimate the movement of funds in and out of the company account within a given timeframe. This is based on the current cash generated from operations as well as the cost incurred (fixed and variable costs) due to the running of the facility.

$$CF = R - \left(C_{fixed} + C_{variable}\right) \tag{4}$$

where CF is the cash flow, R is the revenue, and C_{fixed} and $C_{variable}$ are fixed and variable costs, respectively. While the up-front costs of the RAS components are not relevant for the cash flow analysis, this study provided a rough estimate of the up-front costs to (peri-)urban farming entrepreneurs. The units of all the values are in currency—Naira (₦) and US Dollars (US$).

3. Results

3.1. Mass Balance

The SANFU II RAS started out with 148 African Catfish fingerlings. After 84 days into the four-month growth cycle, 22 African Catfish had achieved a marketable table size of ≥500 g. Given that the fish stock had reached its table size weight, sales activities started. Figure 6 shows the feeding pattern and decrease in stock density due to sales over time. The minimum and maximum daily feed quantity was 12 g and 1.8 kg, respectively. The average amount of daily feed was approximately 0.78 kg, with an average cost of ₦585 (US$1). The efficiency of each of the filtration systems was observed to be 98%, based on the volume of residuals of settleable solids observed in the fish tank. If the aforementioned values are computed for the concentrations of solids out, C_{out}, of the filtration system Equation (2), it will result in a value of 0.015 kg/L.

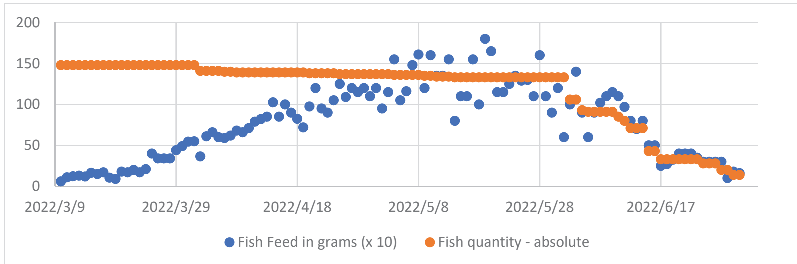

Figure 6. Quantity of fish and amount of fish feed in the SANFU II RAS in one cycle of 4 months. *Source: Authors.*

3.2. Stocking Density

The anticipated length of the African Catfish at the end of the four-month growth cycle is 40 cm. The $C_{Density}$ of 0.34 (default value used for a certain species of fish) was used for the African Catfish to estimate the stock density Equation (3) level of 118 kg/m^3. Considering that the fish tank in use is 0.6 m^3, this implies a stocking density, $D_{Density}$, of 71 kg/m^3. Ebeling and Timmons [49] recommend to start with half of the estimated stocking density as a precautionary measure, which would correspond to 35.5 kg/m^3 given the fish tank measures 600 L. This implies that 71 African Catfish with a table size of ≥500 g should be farmed in the tank. Therefore, the SANFU II project, with its initial 148 African Catfish stocking density, is twice the precautionary recommended capacity based on Ebeling and Timmons [49].

The adequate aquaculture management put in place was able to prevent a high level of mortality. The mortality rate of the SANFU II RAS was 11% and below the 12% for the Catfish mortality rate often observed in aquaculture (see UGA [51]). This is not to say there was no consequence for stocking at a relatively high density as cannibalism was observedsince only 131 Catfishes survived. This resulted in the separation and sorting of the fishes after two and half months. African Catfish above 400 g were transferred to a flow-through system and immediately sold to consumers, while those below 400 g were kept in the RAS. Figure 7 below shows the stocking density of the African Catfish in the micro- and small-scale RAS towards the end of the four-month cycle.

Figure 7. African Catfish yield of the SANFU II RAS in one production cycle of 4 months. *Source: Authors.*

3.3. System Monitoring and Management

The higher the high stocking density of an RAS, the higher the demands on its monitoring and management. The twice-as-high stocking density as compared to the recommended capacity based on Ebeling and Timmons [49] in the SANFU II RAS was compensated with more intense monitoring and management. This entailed cleaning the immense settleable solids and other residues from the filtration system as well as observing fish health on a daily basis. A number of events such as system clogging, water treatment and fish health concerns led to the complete removal and replenishment of the water in the fish tank over the four-month growth cycle. Figure 8 illustrates the trend in water replenishment due to filtration cleaning and the aforementioned occurrences. According to Figure 8, the 100% removal and replenishment of water took place less than 10 times in 114 days or one cycle, alongside the 10 percent water displacement attributed to filtration cleaning and effluent removal (also see Ebeling and Timmons [49]). Compared to conventional flow-through systems in which water is completely replenished every two days, depending on the stocking density, the micro- and small-scale RAS prototype conserves water. Due to the presence of adequate monitoring and management as well as the expertise of the full-time staff member (see Section 3.3) in aquaculture management, the SANFU II RAS prototype experienced a lower-than-average mortality rate. Fish mortality was predominantly due to bacterial infection. For instance, Amponsah and Guilherme [42] argue that bacterial infections account for the majority of mortalities in aquaculture. As a way of minimizing bacterial and fungal infection, a sea salt treatment and antibiotics were applied to the system once a sick fish was identified and separated. Occasionally, the sea salt treatment was also applied as a precautionary measure.

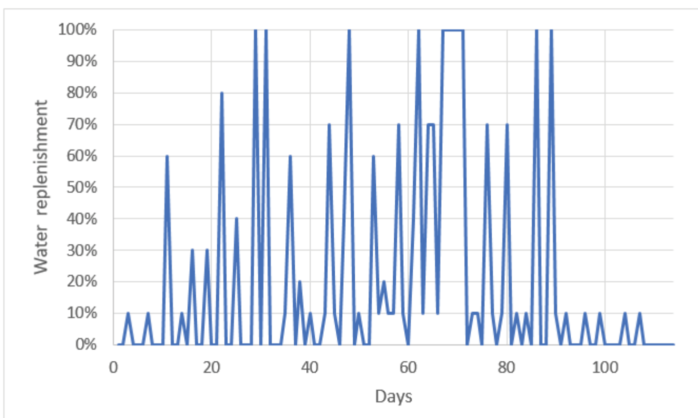

Figure 8. The filtration cleaning and water replenishment in the SANFU II RAS in one cycle. *Notes: Filtration cleaning always took place when the water replenishment was above 5 percent. Source: Authors.*

3.4. Cash Flow of the Small-Scale RAS

The RAS was designed, fabricated and implemented earlier based on donor seed money. It has been running since 2019 and was upgraded in 2022. The up-front costs of the SANFU II RAS prototype, which consist of a 600 L fish tank system (plus sorting and sump tanks), fingerlings, a 2.5 KVA solar system, 10W water pump and aeration device, were estimated at ₦700,000 (US$1200). The cost of the 2.5 KVA solar system (incl. batteries) in Lagos, Nigeria, ranges between ₦300,000 (US$517) and ₦850,000 (US$1465). Thus, the total cost of a complete solar-powered micro- and small-scale RAS would range between ₦1,000,000 (US$1724) and ₦2,000,000 (US$3500) in Nigeria. This cost range is very similar to the average annual income of between US$1046 and US$4095 per capita (in constant 2020 US$) in Nigeria, a lower–middle income country [52]. This comparison highlights the investment challenge to vulnerable groups and poor urbanites (see Benjamin et al. [16]).

Alternatively, solar energy could be sourced from a local green energy provider such as MTN Solar Electricity. The SANFU II project deploys a mixed energy approach in powering the RAS by combining off-(solar) and on-grid electricity to account for electricity needed at night. The average daily running time of the 10W water pump and aeration device was 20 h. The respective price per kilowatt-hour of solar and on-grid electricity in Lagos was ₦58 (US$0.10) and ₦45 (US$0.08), respectively [53]. The expected monthly expenditure on electricity (solar and on-grid) required to operate the RAS is estimated at ₦1233 (US$2), while the salary payable was ₦20,000 ($34). This results in a monthly fixed cost of ₦21,233 (US$36). The monthly variable cost, comprising fish feed (foreign and locally sourced), medication and other operational expenses, is estimated at ₦15,500, (US$27) bringing the total monthly fixed and variable cost of the SANFU II RAS prototype to ₦36,733 (US$63), but this can be reduced to ₦16,733 (US$29) without external labor. A more detailed overview of the total monthly fixed and variable costs is presented in Table 1. Fish feed and external labor make up 37 percent and 54 percent, respectively, of the total cost. The market price of one African Catfish at table size in Nigeria in 2022 was between ₦1000 (US$1.7) and ₦1200 (US$2.1). At the end of the four month production cycle, 115 fishes weighing above 500 g were sold, resulting in revenues of ₦130,140 (US$224). The remaining 16 fishes were used for their own consumption. This implies a monthly revenue of ₦32,535 (US$56). If the average monthly expenses are compared with the revenues, the SANFU II RAS prototype still entails a deficit of ₦4198 (US$7). In the short run, a profit will only be achievable if the paid full-time staff is substituted with family labor. The monthly cost per fish >500 g sold would thus come up to ₦111 (US$0.19) while revenue was ₦283 (US$0.49). We assume that within the family, there is a high level of unemployment given that the current unemployment rate of Nigeria is 33% [54]. These family members could pursue RAS as the alternative to forego productive capacity, losses in national income and social exclusion [55]. In this case, the monthly profit would amount to ₦19,770 (US$34) or ₦172 (US$0.30) per fish sold. It is important to note that the SANFU II micro- and small-scale RAS prototype was implemented on 13.4 m^2 area of land and proves that the implementation of RAS in a (peri-)urban setting in Africa requires minimal land.

Table 1. Overview of monthly fixed and variable cost of simplified RAS in Lagos, Nigeria.

Fixed Cost			
Description	**Unit**	**Amount (₦)**	**Amount (US$)**
Utilities			
Solar system	KWH	696	1.2
On-grids Electricity	KWH	537	0.9
Salary			
Facility manager	1	20,000	34.0
Total fixed costs		**21,233**	**36.1**
Variable Cost			
Fish feed	kg	13,500	23.2
Treatment of disease (antibiotics and sea salt)	kg	1000	1.7
Miscellaneous (Repair, replacement etc.)	1	1000	1.7
Total variable costs		**15,500**	**26.6**
Total costs		**36,733**	**62.7**

Notes: KWH = kilowatt hour. Exchange rate applied here was US$1 = ₦580, which was the average rate observed during the field work. 600 L tank was stocked with 148 African Catfish. Source: Authors.

3.5. Challenges of Sustainable RAS Nigeria

The SANFU II project piloted in Lagos, Nigeria, experienced, on average, 11 h of on-grid power outages per day. The use of an alternative energy source, namely, a 2.5 KVA solar system, made the aforementioned average pump running time of 20 h possible. Figure 9 below illustrates the difference in the number of hours of available on-grid electricity and the running times of water pumps (see green arrows) supplemented by renewable energy. According to Aich et al. [21], such use of new energy sources will be vital in overcoming future challenges and attaining a sustainable blue economy.

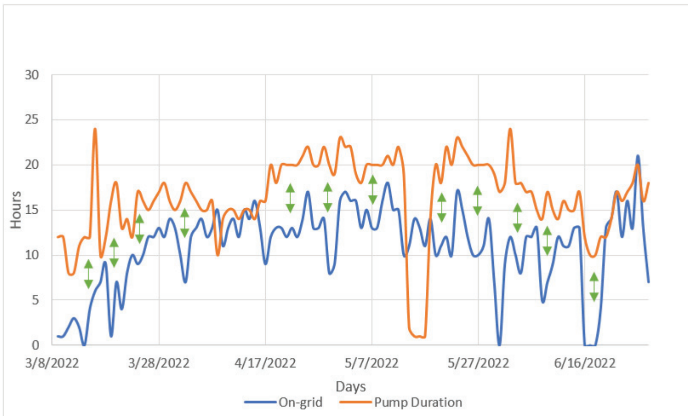

Figure 9. On-grid electricity supply and running time of water pumps in hours per day. Green arrows signify the energy gap covered by renewable energy due to national grid outages. *Source: Authors*.

Input market. There is an immense input market gap (for instance, with regard to affordable and nutritious fish feed and equipment) for RAS if the technology and practices should be adopted as part of (peri-)urban farming in Nigeria and across Africa. The situation of SANFU II project would have been worse but for the availability of some virtual marketing platforms as well as local plumbing and hardware stores. However, the substitutes and alternative equipment at plumbing and hardware stores do not necessarily conform to aquaculture standards.

4. Discussion

Complex system designs of small-scale RAS is one of the factors limiting the adoption and implementation of RAS in developing countries and contributing to food security as the COVID-19 pandemic, conflicts as well as climate extremes exacerbate global food insecurity and poverty for urbanites [19,20,56–63]. The shortage of skilled personnel, energy, inputs and the high-upfront cost have also made the feasibility and profitability of the system questionable, despite its ability to produce more fish per unit area compared to conventional fish farming [21]. This study sheds light on the opportunities and challenges of small-scale RAS in sub-Saharan Africa by investigating a fish production cycle and cost–benefit characteristics of a system implemented under the SANFU II project in Lagos, Nigeria, from March to June 2022 on a 13.4 m^2 space. The technical design of a stable RAS system should have a filtration system able to provide adequate water quality with little or no solid residue in ensuring fish health and survival [49]. The estimated water quality concentration, which is expressed in the leftover particles in a given filter device in kg/L (C_{out}) for the micro- and small-scale RAS of the SANFU II project, was 0.015 kg/L. This modest value attests to the efficiency of the filtration units used for fish wastewater recycling under the SANFU II project, as the value is similar to that of [48]. This system design has minimized the complete removal and replenishment of water in the RAS to less than 10 times during the production cycle compared to over 60 times in a conventional flow-through system for the same stocking density and duration. Thus, this study contributes to the body of literature on sustainable land management and highlights the contribution of small-scale RAS to resource, e.g., water and land, conservation, as well as the reduction of effluents released into the environment.

The design of the SANFU II prototype was able to match the stocking density for African Catfish in conventional flow-through system of 71 kg/m^3. Similarly, Dai et al. [64] found that stocking African Catfish at a density between 35 kg/m^3 and 65 kg/m^3 provides high welfare standards, with higher stocking density hindering certain welfare indicators, such as hematological and biochemical indices. However, van de Nieuwegiessen et al. [65] argue that African Catfish can adapt to higher stocking densities of between 100 kg/m^3 and 300 kg/m^3 in intensive recirculating systems. Hengsawat et al. [66] also found that the high stocking density results in increased catfish harvests and, ultimately, higher profits. The grow out weight of the African Catfish at this stocking density at the end of the four-month period was above 500 g, with a length above 40 cm. Benjamin et al. [4,16] also found that after four months, a length of 40 cm as well as a weight of over 500 g was achievable in African Catfish. Brummet [67] argue that for aquaculture to develop in Africa and provide diverse benefits to society, a business approach that focuses on small- and medium-scale enterprises must be adopted. Thus, the SANFU II small-scale RAS model will enable practitioners, especially vulnerable groups in (peri-)urban areas, to rear fish for subsistence consumption as well as for revenue generation through sales within a short period.

Access to appropriate aquaculture monitoring and management skills is vital for RAS success. Monitoring helps to identify fish diseases and to engage in counter measures, thus reducing losses and costs. The SANFU II project trained and retained a young adult from the host community as a facility manager responsible for water quality and fish health management. The facility manager undertakes filtration maintenance as well as data collection, including the recording of fish growth, pH and ammonia of the RAS. The filtration maintenance was observed to be more frequent as fish growth progressed.

Amponsah and Guilherme [42] argue that fish farming using RAS requires a high initial investment and reliable electricity but is easy to construct on limited space, e.g., in backyard gardens or courtyards. In terms of scaling the project to reach more households, an important question to ask concerns the high initial investment, which can be mitigated through government and private sector funding, e.g., grants, concession loans, guarantee credits, etc. As mentioned earlier, the costs of small-scale RAS implementation is beyond the scope of this study. However, it is important to analyze whether small-scale RAS can sustain itself as an agribusiness once implemented. The cash flow/profitability analysis conducted for the SANFU II project follows this line of reasoning in exploring the cost–benefit of RAS in a (peri-)urban farming context. The small-scale RAS under consideration in this study can become financially viable if households utilize family labor and if the family labor has the appropriate aquaculture management skills. By replacing an external facility manager with family labor, the monthly operating expenses, estimated at ₦20,000 (US$34) of the micro-and small-scale RAS, could be reduced to ₦6000 (US$10). This will also enhance the acquisition of new skills and learning on the job. The use of family labor in (peri-)urban farming, specifically RAS, may not only improve FNS due to improved subsistence consumption, but also make it a profitable and thus viable venture. When family labor replaces external labor and aquaculture management skills are accessible, a monthly revenue of ₦32,535 (US$56) and net cash flow (profit before taxes) of ₦9802 (US$17) could be realized. While still below the daily poverty ceiling of US$1.90 a day, it actually contributes to average family income. These numbers bode well for efforts to improve FNS in (peri-)urban sub-Saharan Africa.

The challenges of small-scale RAS implementation in Nigeria, apart from the aforementioned high investment cost, are related to instable electricity and the lack of adequate inputs. A minimum of 14–16 h of electricity is required to raise hardy fish such as African Catfish or Tilapia. The electricity outages in Lagos, Nigeria, often lasting for hours, are problematic for pumping and recycling fish wastewater and providing oxygen through aeration systems. This decreases water quality and adversely affects fish survival rate. Furthermore, the lack of inputs, specifically hardware, as well as the high variable cost of fish feed is a major concern for small-scale RAS adoption and implementation in Nigeria. Conventional plumping hardware, often used in aquaculture operations in Nigeria, reduces the efficiency of RAS.

Policy Implication

For RAS to be financially viable, acquiring the proper aquaculture management skills is important. Despite the importance of these skills as well as the growing recognition of the role that aquaculture could play in fostering FNS, reducing environmental pressure due to ASF production, aquaculture management skills remain mostly unavailable when consulting the list of extension services provided by extension workers in sub-Saharan Africa [68,69]. Getting aquaculture management skills on the radar of public extension workers is therefore essential, especially for households who might be unable to afford private extension services.

Other areas where policymakers could improve the viability of RAS concern how to reduce upfront and energy costs. Governments should not only prioritize (peri-)urban farming in short- and long-term agriculture and development agendas and city planning, but work on optimizing the already existing energy infrastructure to improve its efficiency. Investing in renewable energy sources (see Jacal et al. [70]) to ease power availability concerns and energy costs of operating RAS systems represents a cost-effective approach. Governments in sub-Saharan Africa could invest in renewable energy to increase the availability of green electricity and make them accessible to the public. Incentives include subsidy provisions, reducing regulatory constraints to encourage private investments, developing a stable regulatory framework that reduces environmental pollution, e.g., introducing a carbon tax can help to mobilize massive private sector investments in renewable energy sources [71].

Finally, technology has an important role to play in further enhancing the availability of RAS equipment and inputs, for instance, online platforms that could improve access to aquaculture inputs and RAS technology. Another useful area is in linking RAS technology developers to potential users to facilitate dialogue between individuals who respectively design and use the technology to create a feedback network. This represents a cost-effective way for users to gain needed expertise to operate the technology, and feedback from users to developers could provide insights on how to further optimize the functionality of RAS technology. An example is the linkage of RAS practitioners and stakeholders to digital innovation hubs (DIHs) such as the SmartAgriHubs.eu or DigitalAgriHubs.eu. This will provide them with access to digital decision support and risk analysis tools as well as access to investors. Public and private policymakers should create supportive frameworks to encourage the development of these platforms. This could be done by providing funding to develop and sustain the platforms, leveraging already existing networks, e.g., extension agencies, to promote and market the platforms to a wider audience and building strong public–private sector partnerships to attract more investors for RAS systems.

5. Conclusions

The majority of fish produced in African (peri-)urban areas is from flow-through aquaculture. Flow-through aquaculture is unsustainable in city region food systems because it requires substantial land and water resources and pressures the environment through effluents. Sustainable (i.e., circular and resilient) and equitable city region food systems with strong production and market connections are a critical foundation for FNS, thriving communities and businesses [5,72,73]. This can be achieved by transforming linear production and midstream components of the city region food system into circular ones [22]. Circularity in a food system context implies reducing the amount of waste generated and changing diets towards more diverse and resource-efficient food patterns. RAS are circular and suitable for the unique context of African cities because they do not require great access to land, water or wealth. RAS has the potential to produce more fish per unit area compared to conventional fish farming. Yet, RAS has not witnessed a broad adoption and implementation in (peri-)urban farming in developing countries. This is attributed to high up-front costs, complex system designs, unstable electricity, limited aquaculture managerial skills, etc.

This study assessed the technical and financial viability of a simplified small-scale RAS prototype stocked with 148 African Catfish and implemented under the SANFU II project from March to June 2022 in Lagos, Nigeria [49]. The low fish mortality rate is attributed to the efficient filtration system as well as adequate monitoring and management of the system. Assuming that the monitoring and management is taken over by a qualified family member, a unit profit of ₦172 (US$0.30) can be achieved. Alternatively, the produced fish could be consumed by the family, thus reducing the purchasing costs for fish protein and contributing to improved FNS.

These results imply that small-scale RAS are technically and financially viable if labor costs are moderate, e.g., through employing paid family labor with proper aquaculture monitoring and management skills. Furthermore, access to adequate equipment and inputs as well as electricity for the recirculating system is crucial. (Peri-)urban innovation actors will only adopt RAS if they are efficient, have low capital and operating costs, and are profitable.

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Smallholders Are Not the Same: Under the Hood of Kosovo Agriculture

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Abstract: Economists and policy makers are interested in producers' responses to policies in order to achieve some national or sectoral objectives, e.g., growth, employment, food security. The way producers respond to policy depends on their production function. If producers do not have homogenous production function, policy responses will be heterogeneous. We use the underlying functional relationship to derive homogenous groupings. The paper employs finite regression mixture models to specify and estimate farm groups with regard to pre-specified functional relationship. The proposed approach is illustrated with regard to the aggregate production function of Kosovo agriculture, characterised by high prevalence of small farmers. The results point out to two farm clusters. The first one extracts more output from labour and intermediate consumption. The second one makes a better use of land. Perhaps, surprisingly, both clusters appear quite similar in terms of their stock of production inputs. Cluster 1 however appears to be more specialised. We can conclude that in Kosovo agriculture appearances and size are not primary determinants of productivity.

Keywords: finite mixture models; production function; land use diversity

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1. Introduction

Economists and policy makers have always been interested in producers' responses to policies in order to achieve some national or sectoral objectives, e.g., growth, employment, food security. The way producers respond to policy depends on their production function. The commonplace assumption that all observed units have homogenous production function leads to expectation of homogenous response [1] which is, however, not particularly realistic. If this assumption does not hold, production units' policy responses will be heterogeneous. This heterogeneity in responses is the focus of the present paper.

Modelling heterogeneous responses has a long tradition in economics, and in particular in agricultural economics in the area of the so called 'representative farm modelling' [1,2]. The traditional approach splits the units of interest into relatively homogenous groups with regard to a set of pre-defined characteristics and models these separately [3–5]. Often the purpose of such modelling is to use the results for mathematical programming models of these different groups. The way these groups are derived can, however, be problematic. Often some form of factor analysis or principal components analysis is applied with regard to selected observable characteristics in order to identify the groups. The problem with this approach is that it yields groups which are similar with regard to the observable variables used in the analysis, but not necessarily with regard to the functional relationship which is of primary interest in such an approach.

In the present application we have an additional issue. All Kosovo farms are small. Furthermore their endowments, as demonstrated later, are quite concentrated. This means that trying to deduce different responses form differences in their characteristics would be challenging. Furthermore, one cannot safely assume that there is a dramatic difference between small-scale farms and the rest, when the rest is virtually non-existent. Hence, while in may CEECs countries a well-defined dualistic farming structure (with a large number of small farms and a very small number of larger ones) provides a natural differentiation in which smallholders coexists with large production units his is not the case in Kosovo. It could be tempting to assume that all small farms are to some extent similar, since they have similar characteristics. Yet, such an assumption would only hold if their response to production incentives is fully defined by their characteristics. Such an assumptions is, however, entirely baseless since it essentially is equivalent to assuming that production functions (the production response) only depend on farming characteristics. The production function, however, is a function of these characteristics and hence such an assumption is equivalent to saying that all farms share the same production function. In this paper we invert the question and ask: given the observed production response, how many qualitatively different production functions are necessary to describe the farming population.

We propose to specify homogeneous groups with regard to the pre-specified functional relationship, in this case a production function. The groups are estimated using finite regression mixture models. We propose this method as the most adequate when the issue in hand is either to investigate policy responses of groups of firms (farms) with similar production function, or to model their production function in a follow-up simulation model. The empirical analysis is focused on the aggregate agriculture production relationship. It provides a farm classification based on the production function which, in contrast to the farm characteristics generally used in the clustering approach, is not directly observable. Examining such a classification for a specific country has distinct policy implications. Different groups of farms, identified using the proposed methodology, are expected to react differently to production incentives and to shock as the most recent COVID-19 and the war in Ukraine, as well as to policy attempts to smooth these shocks, since by definition they have different production functions. Although still there is not systematic farm level management data on the impact of the above shocks, the study in this paper will provide insights to policy-makers whether they should expect harmonized or differentiated response by smallholders to their policy incentives to smooth the consequences of these unexpected shocks. The aggregate reaction of the agricultural sector will be a weighted average of the responses of the different groups.

The proposed approach is illustrated with regard to the aggregate production function of Kosovo agriculture. Kosovo is chosen as a case study since the interest in this paper is on smallholders. Kosovo is one of the poorest countries in Europe. Table 1 compares Kosovo with the other Western Balkan countries, the European Union (EU) and the countries of Europe and Central Asia, excluding the high income ones [6]. The data indicates that Kosovo is consistently the poorest country. Compared to the EU (Kosovo contemplates to join the Union and formally applied for membership in 2022), GDP per capita in Kosovo in purchasing power parity is within the range of one fifth to one fourth of the value in the EU.

Table 1. GDP per capita, Purchasing Power Parity (constant 2017 international dollars).

	2015	2016	2017	2018	2019	2020	2021
Albania	11,879	12,292	12,771	13,317	13,653	13,254	14,520
Kosovo	9445	10,031	10,436	10,755	11,319	10,707	11,579
Montenegro	18,264	18,798	19,682	20,687	21,534	18,259	20,567
North Macedonia	15,139	15,553	15,706	16,146	16,773	15,780	16,464
Bosnia and Herzegovina	12,631	13,194	13,754	14,387	14,897	14,521	15,635
Serbia	15,578	16,183	16,611	17,453	18,307	18,255	19,762
European Union	40,752	41,516	42,678	43,558	44,395	41,721	44,024
Europe & Central Asia (excluding high income)	20,041	20,208	20,830	21,368	21,754	21,350	22,712
Kosovo GDP per capita as % of the EU	23.2	24.2	24.5	24.7	25.5	25.7	26.3

Source: World Bank World Development Indicators. Series: GDP per capita, PPP (constant 2017 international $).

In line with the other countries in the Western Balkans, agriculture is an important sector in Kosovo [7]. Kosovo share of agriculture, forestry and fisheries in the GDP in the period 2012–2020 varied between 7–8% (Table 2), while in the EU it was between 1.6 and 1.7% [6]. Kosovo's agriculture is characterised by serious structural problems. These include land fragmentation, low labour efficiency and high production costs [3]. The majority of farms are very small in physical size. According to the Agricultural Household Survey, carried out by the Kosovo Agency of Statistics, in 2018 there were 108,108 agricultural holdings with total land area of 185,130 ha. In terms of land area, the largest proportion (i.e., 74%) constituted smaller holdings with less than 2 ha, while only 1.7% were holdings larger than 10 ha [7,8].

Table 2. Agriculture, forestry, and fishing, value added (% of GDP).

	2015	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Albania	19.8	19.8	19	18.4	18.4	19.3	17.7
Kosovo	7.7	8.2	7.4	6.5	7.2	7.4	7
Montenegro	8.1	7.5	6.9	6.7	6.4	7.6	6.3
North Macedonia	9.7	9.2	7.9	8.5	8.1	8.6	7.6
Bosnia and Herzegovina	6.2	6.4	5.6	5.9	5.6	6.1	5.7
Serbia	6.7	6.8	6	6.3	6	6.3	6.5
European Union	1.6	1.6	1.7	1.6	1.6	1.7	1.6
Europe & Central Asia (excluding high income)	6.3	6.1	5.5	5.2	5.4	5.9	5.6

Source: World Bank World Development Indicators.

Despite these structural problems, Kosovo agriculture faced by the unexpected COVID-19 shock has been resilient. For example, if the non-food retail trade shrunk, the turnover of food retail in spring 2020 increased in comparison to 2019 [9]. Apart from increasing demand, since people stored food at home, two other factors boosted the resilience of the agricultural sector. First, by the time COVID-19 started farmers had managed to purchase their inputs. Second, the government introduced several measures to support agriculture, e.g., increased subsidies on some perishable products and doubled (as one-off) the amount of direct payments on a range of eligible crop and livestock products [10,11]. Therefore, a stable food demand accompanied by boosted agricultural policy support allowed Kosovo farming sector to adjust to the shock of the pandemic. However, the negative consequences for small farmers, focus of the present paper, have been more exacerbated than could be revealed by the overall agricultural performance. For some period of time they were out of their traditional marketing channels, i.e., local open air markets which were closed during the pandemic. Only large supermarket chains were allowed to continue trading but small farmers were not integrated in the supermarkets' value chains.

The results from our analysis point out to two farm clusters in Kosovo. What is striking in the obtained classification is that these two groups appear very similar with regard to production factors, with exception of capital. Yet, the two groups make very different use of their endowments in terms of the amount of output they manage to extract from each of these production factors. A more detailed characterisation of the differences between the two groups shows that the more productive group appears to be more specialised in a variety of ways.

The remaining of the paper is structured as follows. The next section provides the motivation for the proposed approach in comparison to alternatives. Sections 3 and 4 include methodology and data, respectively. Section 5 discusses the results and Section 6 concludes.

2. Motivation

In this section the authors are motivated to propose a novel methodology. The reasons for this choice are presented hereafter. Economic theory has a longstanding tradition of emphasising uniformity. The principle of the 'representative economic agent' is probably the best known theoretical abstraction in economics. Assuming such uniformity is very useful in deriving theoretical properties helping microeconomic models to be easily expressed into common sense logic. This approach has been very fruitful in producing logical outcomes based on sound principles of rationality. Furthermore, it has also provided a basis for statistical investigation. Since this concept is an abstraction and it is obtained by averaging the reactions of the actual economic agents, the representative agent responses can be obtained by averaging the observed responses of the actual agents. Hence, although directly unobservable, estimating a mean regression type of statistical model implicitly yields the response of the representative economic agent.

This uniformity principle, although useful, has its limitations and has been questioned. From a theoretical point of view, models of bounded rationality which combine two types of representative agents have been shown to be able to produce qualitatively different outcomes. For example, [12] present a model with rational agents and noise traders who behave randomly and interact with the rational agents. One of the surprising outcomes of this model is that the noise traders, who non-intentionally (i.e., randomly) make very risky investments, may under certain conditions end up dominating the market. [13] further investigate this issue, which is now accepted in financial literature [14,15].

The use of typologies is aimed at somewhat relaxing the uniformity principle by accounting for farm heterogeneity. However, the purpose of establishing such typologies is not descriptive, but rather functional [16].

Clusters describing farmer typologies are often created with the intention to derive implications for some policy design [17] or market responses [18]. The idea is that accounting for inherent heterogeneity allows for better aggregation of farm-level responses. For this purpose however individual farm-level responses need to be coherently aggregated [16] in order to obtain reliable results for policy adjustments. To differentiate driving effects, the use of farm types as a consolidated model is particularly helpful [19]. In order to be able to achieve such a coherent aggregation we need two preconditions: first, the groups (types) need to be representative with regard to the desired (i.e., investigated) reaction function and second, we need to be able to identify the relative shares of these types, so that appropriate weighting for aggregating the heterogeneous responses can be established

In this paper, however, we are not concerned with the theoretical challenges to the uniformity principle, but rather with some empirical considerations. A major problem in empirical research is that the theory rarely prescribes the form of the functional relationship between the variables in question. It is essentially not possible to know beforehand the functional form of this relationship. Hence, the problem of 'representativeness', i.e., homogeneity in response, becomes intertwined with the issue of the functional specification. There is a clear trade-off in this area. Using more flexible functional representation reduces this problem, but also makes the interpretation and inference more difficult, and in some cases impossible (as in the case of the curse of dimensionality problem). Using more restrictive functional representations results in more tractable models, but in this case the representativeness assumption is more likely to be violated simply because the used functional representation is inadequate. Therefore, the representativeness condition in empirical modelling is dependent on a given functional specification. In other words, the question of whether the units of analysis exhibit the same relationship is only meaningful with regard to the given functional form of this relationship.

To simplify the issue, the following discussion focuses on the production function, but our argument is equally applicable to other functional relationships. Grouping units of analysis with regard to their production function (or any other functional relationship of interest), we propose in this paper, not only asks the relevant question (i.e., what different functional relationships describe the data) directly, but also makes the classification issue explicitly dependent on the choice of the functional form. It provides a clear definition of the kind of representativeness the researcher is looking at. If the aim is to group farms with similar production function either because this is the characteristic of interest or because the intention is to model their production function in a follow-on simulation model, this is clearly the question that has to be asked. A clustering type of approach, in contrast, asks a very different question. It asks how similar the units appear to be with regard to some predefined observable characteristics. Such a question leaves the issue of 'representativeness' very vague. In contrast to this in many empirical clustering applications the choice of cluster building components such as fusion algorithms or distance measures is not explicitly dependent on the purpose of such classification meaning that the results can impose a certain structure rather than reveal one [20]. The clustering approach also implicitly claims a kind of logically inconsistent universality. For example, one may use some set of 'relevant variables' to cluster units and then assume that the functional relationship is homogeneous within each cluster. However, the same approach could be applied to a wide range of relationships, such as, e.g., cost, profit and production functions. Therefore, the units in the same cluster are assumed to have the same type of functional relationship for all of the above. This is an unrealistic assumption.

Finally, there is another more practical consideration. Economic analysis is often based, as in this paper, on aggregate relationships, which undoubtedly contain unobserved heterogeneity. For example, when one looks at the issue of production function, since technologies are very different for different farm typologies, it is reasonable to consider different production functions for different types of farming typologies, e.g., livestock, crop, vegetables, etc. farms. Yet, doing so, results in a large number of underlying models without actually solving the problem of unobserved heterogeneity, since even within a certain typology different technologies could co-exists, based on characteristics that are not directly observable. Therefore, from a purely practical point of view, there is a trade-off: on the one hand, one would want a small number of functional relationships, but on the other, would want these relationships to encompass both the similarities and differences amongst the units of interest, in this case farms. In other words, subject to the constraints defined by the choice of functional relationship, one wants the best combination of such functional relationships that describes the data. Hence, in our application of the proposed method of classification the main question becomes: how many distinct production functions can describe the output response of Kosovo agriculture and what are their characteristics? In this way, one not only provides a characterisation of an economic sector (agriculture), but also simultaneously determines the behaviour of its production units.

Whenever the policies do not affect the structure of agriculture, i.e., they do not affect the balance (i.e., the weights) of the different groups, the proposed methodology will just provide an approximation to that response (i.e., production function). However, useful such an approximation might be, there are alternatives that can achieve the same result (e.g., using a more flexible functional form). The real advantage is apparent when policies have structural effects and they affect the balance of the classified groups. In this case, the structural change effects can be inferred by examining the differential production responses by different groups.

3. Materials and Methods

We employ finite regression mixture model to specify and estimate farm groups with regard to the pre-specified production function. It is assumed that, conditional on a set of covariates X, y arises from a probability distribution with the following density:

$$f(y|\theta, X) = \sum_{k=1}^{K} p_k g(y|\lambda_k, X) \quad (1)$$

where p_k are the mixing proportions (0< p_k <1 for all k and $\sum_{k=1}^{K} p_k = 1$), and $g_k(y|\lambda_k)$ probability distribution, parameterised by λ_k. This means that y can be viewed as drawn from K different underlying (conditional) probability distributions. The parameters λ_k specify a regression model, i.e., they include regression coefficients, as well as the distribution parameters. In this study, we use a linear regression specification [21,22], but in principle any other parametric specification, could be used instead. The nature of the estimation algorithm is very general and allows for a wide range of specifications. Equation (1) states that the data-generating process for y, conditional on X, is a mixture of regressions. Thus, if y is the output and X are the inputs, this expression states that the data comes from several distinct production functions.

One can obtain the maximum likelihood estimate for the parameters θ by using the Expectation Maximisation (EM) algorithm of [23] and then apply the 'maximum a posteriori' (MAP) principle to assign observations to each of the underlying distributions. The EM algorithm we used in the analysis consists of the following two steps, namely, the E(xpectation) step and the M(aximisation) step. In the E step the conditional probability of observation i belonging to $g_k(.)$ during the m-th iteration for all i and k, is given by:

$$t_{ik}^{(m)} = t_k^{(m)}\left(y\middle|\theta^{(m-1)}, X\right) = \frac{p_k^{(m-1)} g_k\left(y\middle|\lambda_k^{(m-1)}, X\right)}{\sum_{l=1}^{K} p_l^{(m-1)} g_l\left(y\middle|\lambda_l^{(m-1)}, X\right)} \tag{2}$$

where the bracketed superscripts denote estimates for the parameters during the corresponding iteration.

In the M step the ML estimate, $\theta^{(m)}$ of θ, is updated using the conditional probabilities, $t_{ik}^{(m)}$, as conditional mixing weights. This leads to maximizing:

$$F\left(\theta\middle|y, t^{(m)}\right) = \sum_{i=1}^{n}\sum_{k=1}^{K} t_{ik}^{(m)} ln(p_k g_k(y_i|\lambda_k, X)) \tag{3}$$

The updated expressions for the mixing proportions are given by:

$$p_k^{(m)} = \frac{\sum_{i=1}^{n} t_{ik}^{(m)}}{n} \tag{4}$$

The updating of λ_k depends on the parametric specification and, therefore, no general formula can be given. The maximisation step is essentially the standard maximisation routine used to estimate the conditional model given some fixed, determined in the expectation step, mixing proportions. The generic Equation (3) expresses calculating the log-likelihoods for each separate component and maximising the weighed likelihood with weights given by the posterior probabilities $p_k^{(m)}$. Thus, by adapting the maximisation step, a wide range of models could be fitted.

The above description assumes that one knows the exact number of clusters. However, this is typically not the case. Choosing the appropriate number of mixing distributions (clusters) is essentially a model selection problem. One can estimate the regression mixture models for different number of clusters and then selects amongst these. A popular criterion in model selection problems is the Bayesian Information Criterion (BIC) defined as:

$$\mathrm{BIC}_{mK} = -2\ L_{mk} + v_{mK}\ln(n) \tag{5}$$

where m is any model (thus m denotes the choice of the parametric (conditional) distributions $g(.)$ or any combination thereof), K is the number of components, L is the (maximised) complete log-likelihood and v is the number of free parameters in the model and n is the sample size. If the choice of $g(.)$ is taken for granted, then (5) suggests a strategy of consecutive estimation of (m, K) models for $K = 1, 2, \ldots$ until BIC increases. The consecutive estimation strategy also ensures against the danger of over-fitting the statistical model.

The BIC is based on an asymptotic approximation of the integrated log-likelihood valid under some regularity conditions. It has been proven that the BIC is consistent and efficient on practical grounds [24]. Moreover, the whole class of penalised likelihood estimators, of which the BIC is a special class, are consistent [25,26]. The BIC is furthermore approximately equivalent to the popular in information theory Minimum Description Length (MDL) criterion [27]

In order to select a model where in addition to the model fit the ability to define well separated clusters is taken into account, the integrated complete likelihood (ICL) criterion can be used. According to [16], the ICL can be expressed as BIC with an additional entropy penalty term as follows:

$$\text{ICL}_{mK} = -2\,\text{BIC}_{mk} - 2\textstyle\sum_{i=1}^{n}\sum_{k=1}^{K} z_{ik} ln t_{ik} \quad (6)$$

where z_{ik} are the cluster membership indicators. In the present application, one is explicitly interested in the degree of separation of clusters. Hence, the ICL will be used.

The finite regression mixture approach describes the functional relationship as a hierarchical mixture model, where the data generation process generates each observation from a finite set of underlying sub-models, which define separate clusters. As explained in the motivation section, these clusters represent different functional relationships (i.e., different production functions). Hence, the representativeness condition is defined directly with regard to the production function conditional on its functional form. An advantage of the finite mixture approach is the ease by which data observations can be attached to the different underlying production functions.

4. Data and Choice of Functional Form

As explained, the approach to specify homogenous groups of observations based on underlying functional relationship is applied empirically to farms in Kosovo. Empirical estimations are based on data from the Kosovo version of the Farm Accountancy Data Network (FADN) for 2016 [28]. It follows the EU's FADN which monitors farms' income and business activities and provides microeconomic management data based on harmonised questionnaire and national surveys of farmers [29,30]. Funded by the European Agency for Reconstruction, in 2005 a pilot FADN project started in Kosovo with a survey of 50 farms. This network was expanded to 159 farms in 2006, continuing, with an increase in the number of holdings to 300 in 2008 and 394 in 2013 and 2014 [28]. In 2011, as a legal basis setting the criteria for inclusion of farms in FADN and the identification of the annual farm income, an administrative instruction was approved. Until 2012, data was collected by advisory services but since 2013 a specialised company was contracted to collect data in different regions of Kosovo.

A qualitative improvement in Kosovo FADN coverage has taken place since 2016 when a new sample was designed based on the results from Agriculture Census 2014. Agriculture holdings have been classified based on the type of farming and economic size. The sample units of FADN observation covered 54% of total number of agriculture holdings, 91.6% of total standard output, 86.6% of total UAA and 89.3% of total LSU. The data cover information on the farm, land use, production and assets, marketing activities and subsidies [28]. This improved FADN sample is used in this paper.

In the empirical specification the farm output is specified as a function of four inputs, namely capital, labour, land and intermediate consumption (IC). These are the standard production factors in agricultural production routinely employed in production function estimations [31].

Summary statistics for the data are presented in Table 3. Labour is measured in Annual Work Units (AWU) and Land in hectares (ha), while all other variables are in monetary terms, namely in euros. Relatively small farms manage to pass the FADN inclusion threshold, which in Kosovo is low in comparison to other EU Member States in order to reflect the nature of Kosovo farms structure (2000 EUR Standard Output). There seems to be considerable heterogeneity in terms of all variables amongst the farms included in the dataset. Since the mean values for all variables are closer to the minimum than the maximum values, there are more relatively smaller farming units and a very long right tail representing the smaller number of larger farms in the distribution for all considered variables. This distributional feature is not particularly surprising, but any such heterogeneity suggests that the functional relationships amongst these variables may also be heterogeneous. In particular, the considerable differences in terms of size that are evident in the data set could lend themselves to differences in the production relationship, since it is not unreasonable to expect that as farms grow larger, the organisation of their activities changes and therefore the input/output relationship might change too.

Table 3. Summary statistics.

	Mean	SD	Min	Max
capital	5915.07	12,604.81	1.00	188,050.00
labour	1.54	1.90	0.01	41.00
land	10.83	29.51	0.03	650.00
IC	12,640.06	30,059.07	1.00	432,880.00

The key question in the paper is whether the Kosovo farms can be described by the same production function. As already discussed, this question requires specifying the inputs and the functional form for the specific production function. There is extensive literature on the issue of production functions, and their theoretical and empirical properties [32–34]. With regard to the problem in hand, it is advisable to employ a production function specification that is sufficiently flexible, since in a finite regression modelling framework there is a clear trade-off between flexibility and the potential number of homogenous groups, i.e., more flexible functional forms will reduce the number of groups. Here, we employ the translog functional specification.

In the production function literature the term 'flexible' has a specific meaning. According to [35], a functional form can be denoted as 'flexible' if its shape is only restricted by theoretical consistency. The translog functional specification can be restricted to satisfy the homotheticity, homogeneity or separability, but in this application no such restrictions have been applied. The main reason for this is that by avoiding restrictions one can maintain its generality. Furthermore, as our previous argument demonstrates, there is a clear trade-off between flexibility and the potential number of clusters since flexible specifications would result in a smaller number of clusters. Therefore, since the question is whether a single production function specification is sufficient to describe the data, it makes sense to avoid imposing restrictions that could inflate the potential number of clusters.

Although in more recent studies the translog appears to have somewhat fallen out of favour with empirical researchers, it is still the most extensively investigated second order flexible functional form and surely the one with the most empirical applications as its empirical applicability in terms of statistical significance is outstanding [36,37]. Furthermore, the fact that the translog function can be considered as a second order (Taylor series) approximation of a more general production function provides a sound justification in applying it here, since the uncertainty about the production function is a major justification for the present study.

An important reason for the choice of the translog specification is also that it is linear with regard to the parameters, which means that standard linear regression techniques can be used for estimation and testing purposes. In principle, estimating a finite regression model simply requires plugging in the M step an estimation routine for the underlying model, which creates tremendous flexibility since this means that the underlying model can be fully nonparametric. Linear specifications offer considerable savings in terms of computational costs.

5. Results

The model fitting ICL criterion indicates that a single common translog production function is not sufficient to describe the Kosovo farms and points out to two clusters (Figure 1). Furthermore, since ICL accounts for both model fit and cluster separation, this demonstrates that these two clusters are well separated. In practical terms, this means that at least some of the corresponding coefficients are significantly different, resulting in two quite different production functions, subject to the functional restriction of a translog functional form.

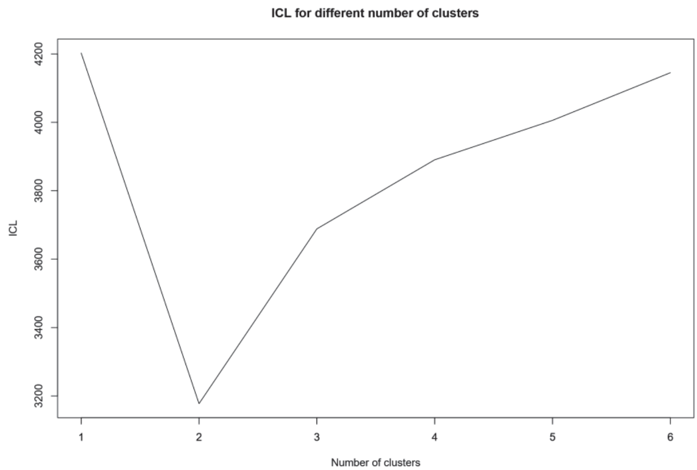

Figure 1. ICL determination of number of clusters.

Table 4 presents some summary statistics for the two clusters. Cluster 1 is considerably smaller with only 144 farms while Cluster 2 contains 1044 farms. In terms of the variables used in the production function, however, there do not appear to be major differences between the two clusters. With exception of capital, where Cluster 2 has more on average and maybe intermediate consumption where it is the other way round, the clusters look very similar in that respect. Since the standard deviations for all variables are smaller in Cluster 1 one may say that it is more compact (in the sense that it exhibits more internal similarity) than Cluster 2. In order to formally check the above propositions, we carried out several tests and their *p*-values are presented in the second part of Table 2. The standard *t*-test for equality in the means is insignificant except for capital implying that only the capital endowments of the two clusters are different. The other two tests – the Kolmogornov-Smirnov (KS) and the Mann–Whitney U-test (which is essentially a two-sample version of the Wilcoxon test) are more general tests for difference in the distributions. As expected, both these are significant for capital (since the cluster means are different, distributions will clearly differ), but they fail to detect any distributional difference for any other factor of production or indeed output. Hence, we can conclude that the two clusters only differ in terms of their capital endowments.

Table 4. Clusters summary and separation.

Clusters Summary							
	Number of Farms		**Output**	**Capital**	**Labour**	**Land**	**IC**
Cluster 1	144	Mean	23,925.97	1220.51	1.46	10.51	15,162.77
		SD	33,126.29	3111.43	1.07	19.39	27,271.16
Cluster 2	1088	Mean	25,116.76	6545.04	1.55	10.88	12,301.53
		SD	83,264.18	13,250.38	1.99	30.62	30,409.38
p-values for tests for differences in the clusters							
T-Test			0.23	0.00	0.58	0.85	0.20
KS test			0.15	0.00	0.39	0.99	0.19
Mann–Whitney U test			0.44	0.00	0.54	0.99	0.98

Yet, our estimation suggests that in spite of looking very similar, the two clusters have very different production functions. Due to the non-linear functional form of these, however, comparing estimated coefficients would be impractical and non-informative. A reliable way to compare two non-linear functions is by comparing their partial correlation plots. This amounts to using the estimated models to predict the dependent variable (i.e., output) and then plot the predicted values against the values for a given factor by keeping the other factors fixed at 'typical' values. In this way, we can visualize the effect of a given production factor when the rest of the inputs are kept fixed. The first issue is what would be the reasonable values for the fixed inputs. This would depend on the purpose of the above plot. If the interest is in average effects, using the average values over the estimation sample would be an easy way to achieve 'reasonable values'. Sometimes averaging would not be a reasonable strategy, in particular in the case of discrete values (see, e.g., [31]). In the present study, all the inputs are continuous variables, therefore, averaging over the estimation sample is used as a viable option.

The second issue concerns the need to create a prediction sample containing a range of values for the input variable of interest, create the relevant (transformed) variables needed in the translog specification and predict from the estimated linear model. The only choice necessary is the range of values for the analysed input. We have employed a regular grid of 100 points defined over the range within which the input in question is observed. Since the two clusters are potentially different in their input mixes, it is reasonable to produce separate ranges for each cluster. In this way, the values for the variable of interest are actually observable within the estimation sample. The resulting plots show the range of values for each input by cluster and this facilitates the interpretation of the results. It also avoids the danger of predicting outside the range over which each of the two clusters is defined. As for the variables over which any such plot is conditioned upon (i.e., the other inputs), averaging over the whole sample is applied in order to ensure that the effects plotted for the two clusters are comparable. Since the summary statistics for both clusters exhibit considerable dispersion, it is easy to verify that such common 'typical' values lie comfortably within the range of observable values for each of the two clusters and, therefore, the synthetic observations created in order to produce the effects of interest are feasible.

Plotting the effects for each input can provide a useful overview of the differences between the corresponding production functions. However, the usefulness of such a comparison would be limited without information on how different statistically these are, which requires confidence intervals for such effects that can be obtained by bootstrapping the corresponding models. Here, we used the nonparametric case bootstrap, following [25].

The partial correlation plots for the inputs are presented in Figures 2–5. Both output and the inputs have been transformed back into the original units in order to facilitate a meaningful interpretation. Due to the non-linear nature of the model, the confidence intervals are asymmetric. The differences in the production relationships are quite striking. Cluster 1 manages to extract more output from labour and intermediate consumption, while Cluster 2 makes more productive use of land. Since the effects are only plotted over the effective range of values for the corresponding inputs, it can be seen that the maximum values for both labour and land (as well as capital) are smaller in Cluster 1. The capital effects only show a tentative picture in that they suggest that Cluster 1 might be able to make a better use of its smaller stock of capital. However, since the confidence intervals for the capital effect in Cluster 1 are quite wide, statistically such a difference cannot be established.

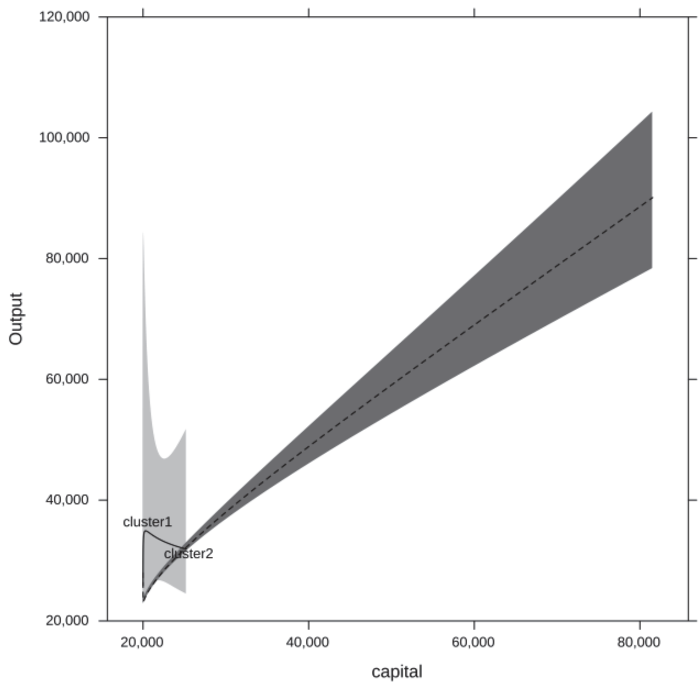

Figure 2. Capital effects by cluster.

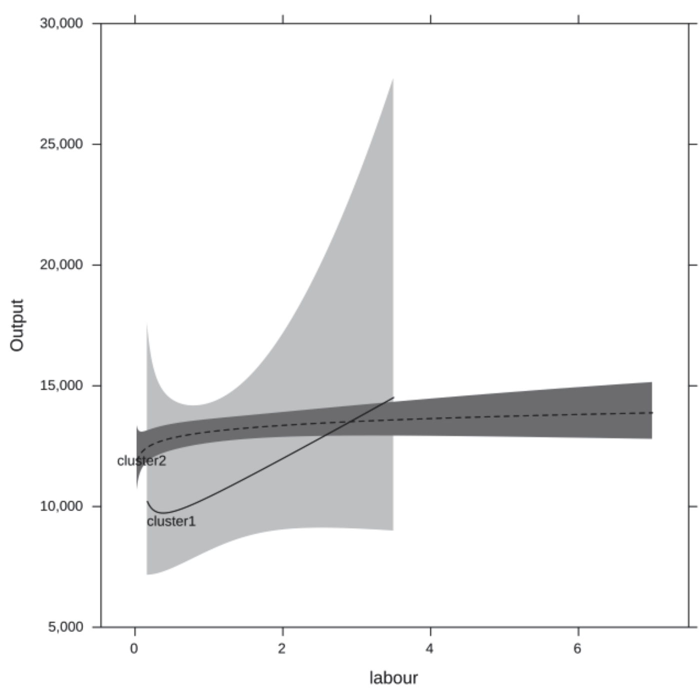

Figure 3. Labour effects by cluster.

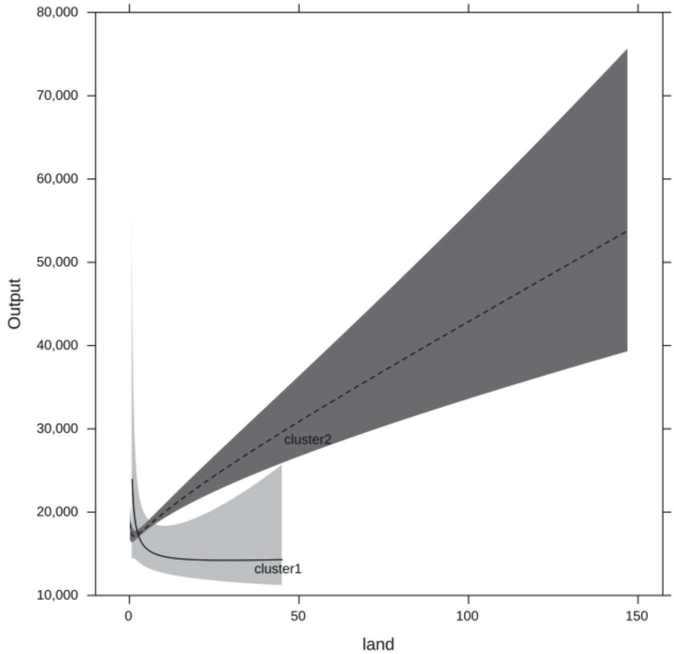

Figure 4. Land effects by cluster.

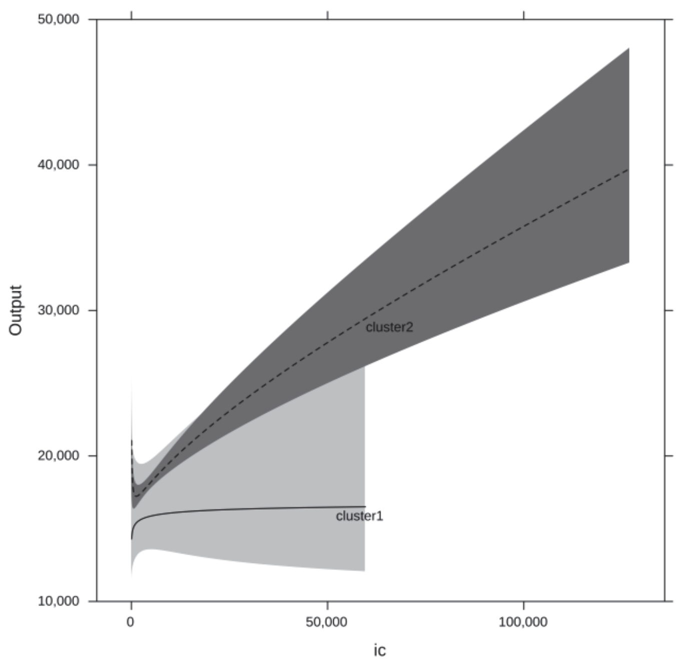

Figure 5. Intermediate consumption effects by cluster.

Furthermore, the partial correlation plots demonstrate a clear differentiation between the two clusters in that the corresponding confidence intervals rarely overlap reinforcing the conclusion that their production functions are markedly different.

Given the similarity of the two clusters and the startling difference in their respective production functions, an important question is about the source of this difference. One of the possible explanations is that these clusters differ in terms of other unobservable, with regard to the empirical approach adopted in this paper, characteristics. Additionally, while some clustering based on a set of such characteristics could always be an option in empirical analysis, it is clear that by modifying the set of such characteristics one may end up with different characterisations, while the approach we adopted here produces unique with regard to the assumed functional relationship groupings. Yet, it would be informative to test whether the two cluster differ with regard to such unobservable characteristics. Another potential source of such difference could be the different types of land use by farms. Cultivating, e.g., different crops, imposes different requirements for labour and capital, as well as different configuration of intermediate consumption. Instead of looking at the multitude of such possible land use configurations, we employed a single measure of the distribution of land use. Three specific measures are applied, i.e., Shanon (entropy) diversity index, richness and the equitability index. The Shannon index is $S = -\sum_{i=1}^{N} \alpha_i ln\alpha_i$, where α_i is the land area share allocated to the ith land use, while the equitability is defined as $E = S/\text{Max}\ (S)$. The equitability index is a standardised Shannon index (divided by its maximum value, so that it fits the [0,1] interval). The richness is simply the number of separate land uses found on a farm.

In simple terms, the above three measures capture the extent to which land use is concentrated or more evenly spread amongst different types of uses. The idea is that more specialised farms will be characterised by a lower values across all these measures. Furthermore, the distribution for any of the above measures will reflect the extent of multiple land use within the farms and, hence, by comparing the corresponding distributions one should be able to reflect on the difference in the two clusters. Unfortunately, the Kosovo FADN only provides a rough classification of land use consisting on 12 different types of use. It does not, for example, distinguish between the different types of cereals. However, this is probably sufficient for our purposes since crops within the same group (e.g., oilseeds or cereals) typically have similar production technologies.

Table 5 presents some summary statistics concerning the distribution of these measures within each of the two clusters. In particular, the table presents the overall range minimum and maximum, alongside the empirical quartiles and the means for each cluster. A look at these summaries suggests that the values for all such statistics is typically larger for Cluster 2, hinting that Cluster 1 may be more specialised, which could explain its higher productivity. To check this conjecture, we tested tor difference in means and distribution, as before (in Table 2). All these tests, with exception of the (non-parametric) Mann- Whitney U-test for equitablity index, suggest that the underlying distributions are indeed different. One can therefore confirm that Cluster 1 is more specialised than Cluster 2.

Table 5. Land use differences between the clusters.

		Min.	**1st Quartile**	**Median**	**Mean**	**3rd Quartile**	**Max.**
Shannon Entropy	Cluster1	0.00	0.00	0.54	0.39	0.67	1.26
	Cluster2	0.00	0.20	0.58	0.49	0.69	1.38
Richness	Cluster1	1.00	1.00	2.00	1.75	2.00	4.00
	Cluster2	1.00	2.00	2.00	1.99	2.00	5.00
Equitability	Cluster1	0.00	0.00	0.43	0.31	0.53	1.00
	Cluster2	0.00	0.14	0.42	0.35	0.50	1.00

	Shannon Entropy	Richness	Equitability
T-Test	0.00	0.00	0.09
KS test	0.01	0.01	0.00
Mann–Whitney U test	0.00	0.00	0.40

6. Conclusions

In this paper we used finite regression mixture models, based on an underlying relationship of interest for classification of heterogeneous units of analysis. We applied the proposed approach to Kosovo farms production function.

The results suggest that there are at least two clusters with distinct production functions. While these two clusters appear to be similar in terms of their aggregate inputs, they have very different production functions. Cluster 1 is much smaller in terms of number of farms but manages to extract considerably more output from most inputs with the exception of land, whilst Cluster 2 is more productive. What is particularly interesting is that while being similar in many respect, the one difference between the two clusters is the capital endowments since Cluster 2 has much more capital. Yet, in contrast to conventional thinking, more capital does not extend to higher productivity. In fact, it is Cluster 1 which manages to make more productive use of its inputs. The main reason for this differential productivity performance appears to be the higher level of specialisation of Cluster 1.

It would be useful to consider how such production system might respond to external shocks. The general economic shocks could be expected to increase unemployment implying more labour supply to agriculture. This would benefit Cluster 1 which extracts more output from labour. Yet, this is the smaller (in terms of number of farms) cluster. Hence, the positive labour effects would be somewhat limited. Cluster 2 has higher absorption capacity for the extra labour. It extracts more output from land, which is in restricted supply, meaning that land is essential for allocating the surplus labour. As we have discussed, Cluster 2 is also more diversified in terms of different uses for its land. Such a diversification is an expected livelihoods supporting strategy. It could therefore be expected that crises and external shocks would lead to relative growth of Cluster 2. Yet, the production potential is clearly in Cluster 1. This suggests that agricultural policies should be more focused on enabling the growth of this particular cluster.

The analysis in the paper has several limitations which we intend to deal with in future work on small farmers. The proposed approach is explicitly conditioned on a predefined functional relationship. Re-appraising the latter in both functional form or additional characteristics of interest would allow one to better tune the empirical application with a more focused research context. Furthermore, although the present application used a cross-sectional data, it is straightforward to extend to a longitudinal data contexts, where a more detailed insight could be obtained.

An external constraint we faced is that the collection and finalization of FADN data normally takes several years before the network is ready for analysis and could be accessed. Our data precedes the external shocks of COVID-19 and the war in Ukraine. We would like to repeat this study with more recent data which will allow to see the impact on small farmers and their adjustment process. Such an analysis calls for a longitudinal study.

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Assessing the Outreach of Targeted Development Programmes—A Case Study from a South Indian Village

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Abstract: This paper explores beneficiary targeting of government programmes in a village in India. The analysis is based on all 228 households of the village and focus group discussions. The results show that there is a large exclusion error in targeted programmes, which have mostly excluded the poor and the needy. Most schemes have a prerequisite of asset ownership, such as agricultural land, which benefits resource-rich farmers with large landholdings. The relationship between benefits received and income of households is best represented by an inverted 'u'-shape curve, indicating the middle-income category benefits more than the poorest. The scope and scale of welfare programmes, especially Direct Benefit Transfers, increased during the COVID-19 pandemic. For inclusion of the poorest of the poor, welfare and development schemes need to be decoupled from landownership in rural areas.

Keywords: development programmes; welfare schemes; beneficiary; targeted schemes; socially disadvantaged groups

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1. Introduction

Ending all forms of poverty across the globe is the first goal of the 2030 Sustainable Development Goals (SDGs). Historically, the Universal Declaration of Human Rights of 1948 recognizes the right to social protection in order to make economic growth inclusive. Though the concept of a social safety net dates back to political economists such as Adam Smith, Condorect, and Turgot [1], with the impending deadline of the SDG target, the time has come to look at the performance of poverty alleviation policies and assess if they truly target and benefit the poor. In response to this, governments across the world are increasing their welfare and development budgets. Similarly, the central and local governments in India have also initiated a plethora of programmes and schemes, mainly to address the needs of the poorer households in the society. Some of these schemes are universal, such as a subsidy on cooking gas, a midday meal scheme for school children, pre- and postnatal care and assistance for women etc., while some specifically target households below the poverty line, such as distribution of food grains at subsidised rates.

Poverty is an extremely complex phenomenon, and it manifests itself in a range of overlapping and interwoven economic, political, and social deprivations [2,3]. The programmes and policies aimed at overcoming deprivation and alleviate poverty need to assess "who" is poor and "why" they are poor. Such programmes also require thoughtful investments both in terms of "how much" to invest and in "how" to invest. Hence, targeted development programmes need to carefully select beneficiary households or individuals to both deliver the maximum impact and to optimally use the funds allocated for them.

Targeting is especially important in countries such as India that are characterised by tight fiscal situations with a large poor population in absolute terms. Given the higher levels of poverty, malnutrition, and underemployment, it has become mandatory for the government to provide income support through subsidies, productive employment opportunities, and social security schemes in rural India [4,5]. Such interventions also include development schemes such as health insurance, subsidised treatments, free education for children, pensions for the elderly and widows, surplus land distribution for the landless, and subsidies to purchase fertilizers, seed, and farm machinery [6]. Many of these programmes are supported by multilateral and bilateral donors who strongly hope to contribute to ending poverty in India. Though the central government allocates funds for poverty alleviation, state governments are the key to India's progress on the SDG Agenda, as they are best placed to 'put people first' [7]. To ensure that 'no one is left behind', India needs policies that reach its targeted beneficiaries for optimal resource utilization and fulfilment of its goal of poverty eradication.

This paper makes an important contribution to address the host of practical, ethical, and political concerns with respect to beneficiary identification for targeted development schemes in India. The paper seeks to investigate the effectiveness of targeting mechanisms of various welfare and development schemes in operation in Kunkudupamula Village of Telangana State in India. It seeks to understand whether the investments in development and social welfare schemes actually benefit the socially and economically weaker sections the schemes target more than the well-off sections.

2. Literature Survey

There seems to be weak mapping the nature of poverty reduction programmes to methods of targeting across regions of the world. Studies have noted dominance of cash transfer programs in Eastern Europe, Central Asia, and Latin America; universal food subsidies in the Middle East and North Africa; and a mixture of cash and food transfers in South Asia [8–13].

A number of authors have defined targeting efficiency indicators with a view to identify best targeting practices [14], each having its own advantages, drawbacks, and different degrees of relevance and appropriateness depending on the particular socio–economic context or country under which it is implemented [15]. Means testing methods that identify the poor based on direct measurement of income/consumption/standard of living of households or individuals is used for direct cash transfer policies and is particularly popular in Africa and Latin America [16].

Geographic targeting is widely followed in developing countries within certain geographic areas [17]. It is very popular in India, where there is large concentration of poor in rural areas. Demographic targeting aiming to distribute meals and nutritional supplements to vulnerable population such as preschool children, pregnant and lactating mothers, and women of childbearing age from low-income households are popular in South Asia [16,18].

Given that India is struggling with high fiscal deficits and budget constraints, self-targeted schemes are preferred over universal schemes. In these two types of targeting, (i) individuals recognise the need to be beneficiary or (ii) the local administration/authority identifies the beneficiary. For example, under the Mahatma Gandhi National Rural Employment Act (MGNREGA—the largest employment guarantee programme in the world, which guarantee 100 days of casual employment to individuals who opt to work in their own villages), individuals recognise the need to be beneficiary. Generally, it is assumed that only poorer households opt to work under this scheme as it provides only casual, unskilled work with a low wage. However, because of its universal accessibility, low work intensity, off-hours (from 6 a.m. to 10 a.m.) and transient nature, many non-poor individuals take part [19]. Hence, self-selection gives people the chance to decide for themselves whether they work under an employment guarantee scheme or not, irrespective of their poverty status [20]. On the other hand, under the Public Distribution Scheme (PDS), the government/administration identifies beneficiaries based on their income status. Under this scheme, only households below the poverty line are eligible to receive subsidised food grains.

Despite being one of the fastest growing economies in the world, India is home to the largest number of poor people in the world, making poverty reduction a challenge [21]. It is now established that trickle-down effects do not work in developing countries such as India [22]. Development has remained confined to urban areas [23], and rural areas, where more than three-fourths of the country's poor reside, remain deprived. A deep-rooted caste hierarchy also reinforces social distance between the privileged and the rest [24]. Today, the socially disadvantaged and marginalised population still suffers from hunger, poverty, and deprivation [25].

3. Methodology

The study was conducted in Kunkudupamula Village. As India has 600,000 villages, due care was taken while selecting this village so that it would represent an average village in India in terms of population size, landholding, socio–economic composition of population, share of nonfarm activities, and economic activities. The study followed a mixed method approach. All 228 households in the village were selected for an intensive field survey, and a list of farmers was taken from the 2011 village census, with additions (if a household immigrated after 2011) and deletions (if a household emigrated after 2011) were done to cover all the households residing in the village as of the interview date (Table 1). A structured household questionnaire including the general summary of the household, the land and agricultural profile, various household liabilities (including loans), and details of benefits received through various government schemes was developed to understand the linkages between household socio–economic characterization and benefits received by each member of the household. To compliment the analysis, focus group discussions and interviews using semi-structured questionnaires were conducted to understand the actual benefits received by beneficiaries and reasons for exclusion. The semi-structured questionnaires covered various aspects such as the evolution of cropping systems, predominate crops, cost structures, levels of tenancy, tenancy rates, credit availability to households, interest rates and repayment culture, labour markets, frequency and causes of out- and in-migration, employment opportunities other than agriculture, the status of youth and women in the village, scheme effectiveness/utility, the level of corruption, the process of filling up application forms, frequency of visits the local office to enroll as a beneficiary, prevalence of benefit usage, and ways in which people had used benefits. These semi-structured questionnaires were completed by interviewing village elders, educated teachers, agricultural officers, rural development officers, etc. Further, separate focus group meetings were organized among farmers, women, youth, and scheduled caste and tribe households, as within the village, women, youth, and scheduled caste (socially disadvantageous group) households are not able to tell their problems openly in larger groups in front of males, parents, and forward caste (socially advantageous) households, respectively. The key opinions of these groups are presented while discussing the results.

Table 1. Demographic details.

	Category	No. of Households	Average Family Size	Average Years of Schooling by Head of Household	Average Age of Head of Household	Land Holding (Acres)
Social Group	SC	47	3.6	2.7	56	1.2
	OBC	118	4.2	3.6	53	2.7
	FC	63	3.8	5.1	56	4.4
Landholding	Land less	79	3.5	4.4	52	0.0
	Marginal	46	3.8	1.7	59	1.2
	Small	54	4.3	4.8	51	3.3
	Medium	44	4.3	3.2	59	7.2
	Large	5	5.8	7.0	52	19.8
Poverty	BPL	97	5.2	7.7	51	1.95
	APL	131	3.0	6.4	57	3.50
	Total	228	4.0	3.8	55	2.8

Source: Data collected and compiled from field survey in Kunkudupamula Village. Note: 1. Government of India classifies some of its citizens based on their social and economic condition, such as Scheduled Caste (SC), Other Backward Class (OBC), and forward caste (FC), or others who are not in any category. The SCs are among the most disadvantaged. 2. The study was conducted in year 2016–2017; during this period average exchange rates were INR 20.65 = USD 1.00 purchasing power parity (PPP). USD 1.90 PPP per capita per day poverty line is equivalent to INR 14,319.39 per year. Based on this, all households falling below this threshold were classified as below poverty line (BPL) or poor, and above it were classified as above poverty line (APL).

4. The Study Area and Development Schemes

Kunkudupamula is a village located in the Nalgonda District of Telangana State in India (Figure 1). With a population of 903 and a geographical area of 546 ha, this remote village is located 60 km from the district headquarter. Though the village is connected by all-weather roads, transport facilities remain very poor, with the nearest railway 10 km away. The village has electricity and a mobile network. There is no postal or courier service. There is only one primary school. There is no primary health care centre. It has a basic maternity and childcare centre (Anganwadi Centre). There is a fair-price shop where people can buy subsidised food items as allocated in the PDS.

The low level of education (Table 1) among the villagers manifests as a pool of unskilled and semi-skilled workers. This is reiterated in the occupation structure of the respondents, most of whom are cultivators or agriculture labourers (Table 2). Agriculture is the primary occupation in the village. Although the average landholding of the FCs is significantly larger than that of OBC and SC households (Table 1), income does not vary significantly between them (Table 2). This may be due to significant earnings made from secondary occupations, mostly livestock rearing. Since the 2000s, opportunities from other nonfarm sources, such as construction, services (i.e., watchman, drivers), factories, and petty business have also contributed to additional income. Nevertheless, most SC families in the village continue to remain poor. Families belonging to the OBC community are slightly better off, and those of the FC community remain resource-rich with higher levels of household income. The average income level of the village is slightly below the national average and international standards of poverty (USD 1.90 PPP/capita/day) [26].

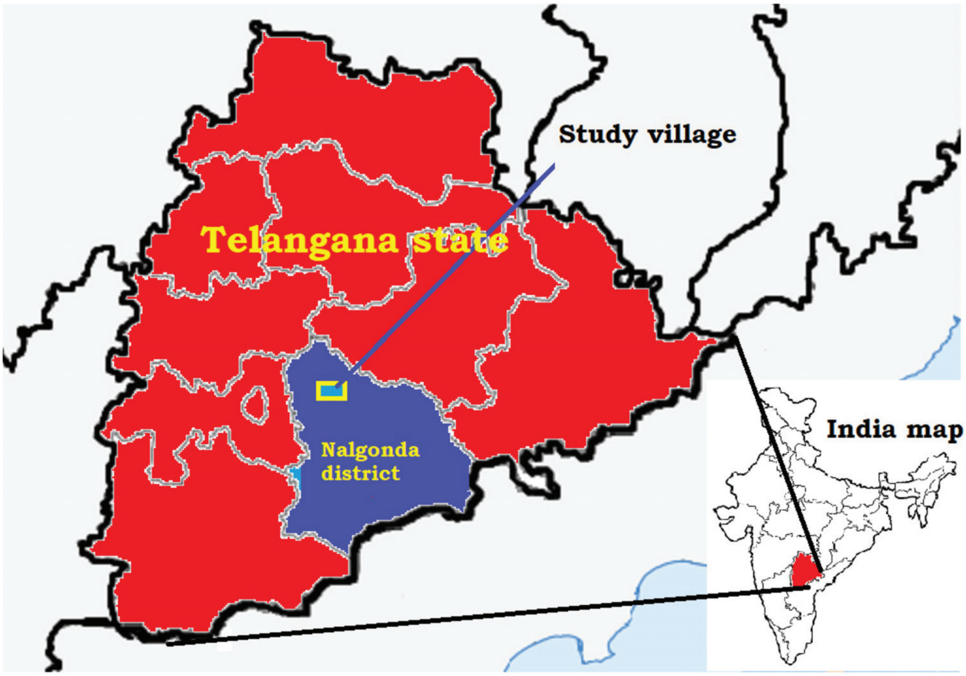

Figure 1. Location of study village (Kunkudupamula).

Table 2. Distribution of workers by main occupation (averages in percent).

Economic/Social Categories	Occupation			Per Capita Income	
	Agriculture	Agricultural Labour	Non-Agriculture	INR per Year	USD PPP per Day
Caste and social category					
OBC	64.4	25.4	10.2	18,125	2.40
FC	68.3	23.8	7.9	24,676	3.27
SC	66.0	29.8	4.3	17,509	2.32
Land holding category					
Landless	12.7	63.3	24.1	17,456	2.32
Large	100.0	0.0	0.0	27,911	3.70
Marginal	93.5	6.5	0.0	18,436	2.45
Medium	93.2	6.8	0.0	24,850	3.30
Small	94.4	5.6	0.0	19,559	2.60
Income and Poverty					
BPL	58.8	27.8	13.4	10,857	1.44
APL	71.0	24.4	4.6	26,436	3.51
Total	65.8	25.9	8.3	19,808	2.63

Source: Data collected and compiled from field survey in Kunkudupamula Village.

A number of welfare schemes are run by the state; however, to contextualise our findings we will focus on the schemes availed by our respondents in the study village. The welfare schemes availed in the study village can be broadly divided into three types.

First are the schemes that target farmers for increasing agricultural productivity and supporting their incomes. Among these schemes, free agricultural electricity, seed and fertilizer subsidies, soil health cards, and farm loan waiver schemes target all farmers, while the remainder demographically target economically and socially disadvantaged groups among the farmers. The state supplies electricity to all farmers free of cost to run electric pumps to irrigate crops. The state gives INR 4000 (USD 52) per acre twice a year to all the farmers to cover the costs of major inputs such as fertilisers, seeds, and pesticides. The government, in order to free all the farmers trapped in perpetual indebtedness, waived outstanding agricultural loans. However, this scheme covers only institutional loans and does not cover loans from non-institutional sources, such as money lenders. Soil health cards are a central government scheme that assists farmers to scientifically test soil samples from farmlands to help with cropping decisions and input use. Rashtriya Krishi Vikas Yojana provides tarpaulins to farmers on a 50% subsidy to cover their crops and grains.

Second, there are schemes that specifically target women who are vulnerable due to their special needs. To prevent malnutrition, pregnant and lactating women are provided one full meal consisting of rice, lentils, and vegetables for a minimum of 25 days, and a boiled egg and 200 mL of milk for a month at the Anganwadi Centre, along with iron and folic acid tablets, locally known as the Arogya Lakshmi Scheme. This scheme also provides facilities for health check-ups and immunization to pregnant and lactating women. It aims to reduce infant mortality, maternal mortality, incidence of low birthweight babies, and anaemia among women. Another scheme called the Kalyana Lakshmi Scheme gives economic assistance to all newly married brides with a minimum age of 18 years belonging to SC, ST, and minority households. In families with limited resources, child marriage is often seen as a way to provide for their daughter's future. This scheme claims to prevent early marriages and to enhance the literacy rate among girls since the money cannot be claimed for marriages of girls who are younger than 18 years. Abhaya Hastam is a special insurance and pension scheme for women who are above the age of 65 years and were active members of self-help groups (SHGs).

The third type of schemes are general welfare for poor families, such as wellbeing, income, and livelihood support. The MGNREGA programme offers 100 days of manual wage employment in a year in rural areas to every household whose adult members volunteer to do unskilled manual work. Both men and women can work at a daily wage of INR 245 (USD 3.2) per day. The PDS provides basic food items (rice, wheat, sugar, kerosene, etc.) to rural ration cardholders at fixed prices through a network of Fair Price Shops. Beneficiary families with income under INR 150,000 (USD 1972) are given 6 kg of rice per person without any ceiling on number of members in the family at INR 1 per kg. Aarogyasri is a medical insurance scheme that provides BPL families with quality medical care for treatment of identified diseases involving hospitalization, surgeries, and therapies through an identified network of healthcare providers. The entire premium is shouldered by the government. The gas subsidy scheme provides 12 subsidised LPG cylinders per year to all households. The subsidy amount is directly transferred to the beneficiary's bank account. To achieve universal sanitation coverage and "an open defecation free India", the state has launched the Swachh Bharat Telangana Mission that offers poor rural households financial help to construct latrines.

In addition, there are some programmes targeting population with specific needs. To support the traditional shepherd communities known as Kurumas and Yadavas in Telangana, distribution of sheep on subsidy was launched, where every person older than 18 years old from shepherd community is given a 75% subsidy on a unit of sheep, which consists of 20 sheep and a ram. The Aasara Pension Scheme provides financial assistance for the daily minimum needs of the economically weaker sections in the state, aged between 58 to 65 years, widowed, destitute, AIDS patients, weavers, and needy tribal people. A fee reimbursement scheme gives 100% financial assistance to students belonging to poor SC, ST, and "BC" (sic) families enrolling in higher education.

5. Results and Discussions

5.1. Number of Beneficiaries and Amounts Disbursed

Among the programmes currently being implemented in the study village, the highest percentage of beneficiaries is noted for the gas subsidy programme (Figure 2). This programme follows a universal targeting method, and all households that use LPG cylinders for cooking benefit. Though many respondents claimed that the subsidy is meagre, the scheme indirectly promotes the health and wellbeing of women, as they are almost universally responsible for cooking for their families. LPG cylinders support gas ovens, which are smokeless and save time and effort in cooking. The second largest in terms of beneficiary reach is the PDS. The villagers are very satisfied with the system as they can conveniently avail all the allocated rationed items within the first half of every month.

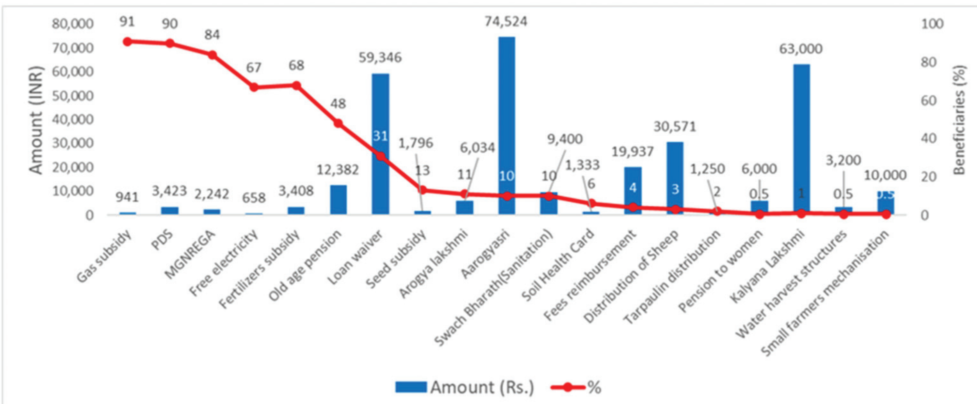

Figure 2. Beneficiary households (% of total) under different schemes and average amount.

The other programmes with large beneficiary groups are the self-targeted MGNREGA and demographically targeted schemes that distribute subsidised agricultural inputs to farmers. Although there were mixed responses about the procedure and timeliness of wage reimbursements, most people in the village who worked in MGNREGA did not have their own farm or business. Thus, it has definitely helped the unemployed and the landless, and has kept a competitive wage rate for manual labour in the village. Similar studies have also noted a higher percentage of the poor participating in and benefitting from MGNREGA [27–29], as it enhances their purchasing power [30]. At the same time, many non-poor individuals also take part in such programmes [19], but in our study village this was not the case. Instead, some farmers we interviewed raised concerns over shortages of agricultural labourer and rising wage rates. This situation is a result of casual labourers opting to work in MGNREGA and demanding higher wages to work on private farms for agricultural operations. These farmers suggest that wage payments for agricultural operations on private farms should also be eligible to get funds under MGNREGA so as to avoid the repercussions from rising wage rates triggered by MGNREGA.

In terms of monetary benefits, the highest disbursement has been for agricultural loan waivers for farmers, benefiting around 30% of surveyed households (Figure 2). Small outstanding loans up to INR 25,000 are waived in the first phase, followed by larger amounts, with a maximum limit of INR 100,000. Some farmers with large loans expressed dissatisfaction with the scheme, and some lamented that it required a lot of paperwork and a long waiting time for disbursement. Furthermore, some farmers complained that the government delayed payments to banks, and as a result, they are unable to take out fresh loans. On the other hand, bankers complained that it affects the repayment culture among farmers, reducing disbursal of fresh loans. The other two programmes giving large pay-outs were Aarogyasri and Kalyana Lakshmi. Despite the fact that Aarogyasri, a health insurance scheme, has a maximum limit of INR 500,000, the fund is only available for the cost of surgeries and inpatient treatment; hence, beneficiaries still have to bear the cost of medicines and outpatient treatments. In the case of Kalyana Lakshmi, every person who applied for the scheme received the benefit amount, but there was general concern about delays in getting the money. However, the unique thing about this scheme is that it is only available for brides of 18 years and above, and the money was directly transferred to the bank account of the bride's mother, focusing on gender empowerment.

5.2. Benefits by Social Groups

If we look at the social category of the beneficiaries of the programmes and the money disbursed (Figure 3A,B), it shows all SC households are covered by the PDS scheme, followed by the gas subsidy (95.6%), MGNREGA (91.3%), and the fertiliser subsidy (67.4%). However, none of the SC category households benefited from water harvesting structures, Kalyana Lakshmi, or the Small Farmer's Scheme. Most probably, SC households could not avail the Kalyana Lakshmi scheme as either they did not have bank accounts or their aughters were married before the age of 18. Some earlier studies have noted that in programmes that involve direct cash transfers to beneficiaries, they do not reach the transient poor in most cases [31], and have the disadvantage of costly documentation [32]. Nevertheless, with the nearly universal bank accounts of households, beneficiaries of this study get timely benefits with less intermediation cost. Many respondents did not know about the water harvesting structure scheme, and many believed there should be more schemes specially targeting SC households.

Of all the programmes, loan waivers account for the largest amount. The FCs benefitted most from this scheme. On average, the amount crop loans waived was INR 61,000, INR 49,385, and INR 32,231 (USD 803, 650, and 425) for families belonging to FCs, "BCs" (sic), and SCs, respectively. Arogyasri also accounted for huge sums of money across all three caste groups, but only for a few households. It involved INR 50,000, INR 48,900, and INR 43,333 (USD 659, 644, and 571) for families belonging to FC, "BC" (sic), and SC, respectively. The subsidy to purchase sheep and the Kalyana Lakshmi schemes benefited the "BC" (sic) families the most, but only a few households benefited from both schemes.

5.3. Benefits by Landholding Class

The Telangana government supplies 24 h/day of free electricity to run irrigation pump in the state. It is available to all farmers who have tube-wells fitted with electric motors and electricity connected to their farms (Table 3). Most of the poor who were either landless or marginal or small farmers did not benefit from this input subsidy as they did not own any wells. Earlier studies have also noted that the free electricity subsidy only favours the resource-rich, tube-well owners, furthering inequality among farmers in the villages [33].

More than half of the landless and marginal farmers benefited from Aasara pension's scheme. However, the respondents who benefitted from this scheme complained about irregularity and delays in starting the pension. Some even confided that officers concerned with the pension had to be offered kickbacks to complete the process. Only 2.3% of medium farmers benefited from the water harvesting structure scheme, as there was a lack of water structure construction in the village.

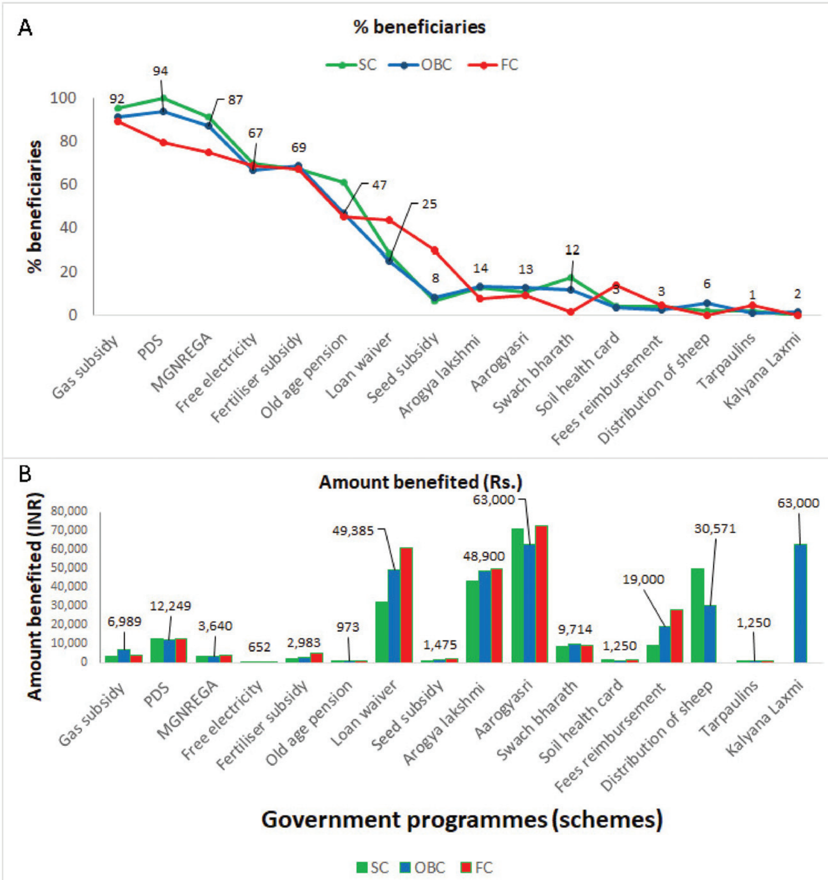

Figure 3. (**A**) Beneficiary households (% of total) under different schemes by social group (**top**); (**B**) average amount benefited in Rupees (**bottom**). Note: women's pensions, small farmer's mechanisation, and water harvest structures are not included as the beneficiaries are less than 1%.

Table 3. Average amount benefitted by households under different schemes (INR).

Schemes	Landless	Marginal	Small	Medium	Large
Gas subsidy	936 (83.5)	913 (93.5)	958 (98.1)	1023 (95.5)	1100 (100)
PDS	3285 (96.2)	3634 (100)	3742 (98.1)	3830 (68.2)	5376 (60)
MGNREGA	2509 (86.1)	2678 (80.4)	2325 (98.1)	2187 (72.7)	2167 (60)
Free electricity	600 (12.7)	573 (97.8)	604 (94.4)	757 (100)	1080 (100)
Fertilizer subsidy	4618 (7.6)	1448 (100)	3313 (100)	4471 (100)	8163 (100)
Old age pensions	12,314 (53.2)	13,000 (65.2)	11,783 (42.6)	12,750 (36.4)	0 (0)
Loan waiver	0 (0)	32,909 (23.9)	57,633 (55.6)	64,692 (59.1)	100,000 (80)
Seed subsidy	0 (0)	1250 (4.3)	1521 (25.9)	1696 (31.8)	3500 (40)
Aarogya Lakshmi	8182 (13.9)	4365 (10.9)	40,00 (11.1)	4000 (6.8)	3413 (40)
Aarogyasri	83,333 (11.4)	62,500 (8.7)	65,000 (20.4)	27,000 (4.5)	0 (0)

Table 3. *Cont.*

Schemes	Landless	Marginal	Small	Medium	Large
***Swach Bharath* (sanitation)**	3000 (1.3)	9125 (17.4)	10,500 (18.5)	8500 (9.1)	0 (0)
Soil Health Card	0 (0)	0 (4.3)	1357 (13)	1333 (13.6)	0 (0)
Fees Reimbursement	12,000 (5.1)	9250 (4.3)	46,500 (3.7)	0 (0)	0 (0)
Distribution of sheep	21,000 (1.3)	40,667 (6.5)	30,333 (5.6)	30,000 (2.3)	0 (0)
Tarpaulins	0 (0)	1250 (2.2)	1250 (5.6)	0 (0)	1250 (20)
Women's pension and insurance	0 (0)	6000 (2.2)	0 (0)	6000 (2.3)	0 (0)
Kalyana Lakshmi	0 (0)	0 (0)	75,000 (1.9)	51,000 (2.3)	0 (0)
Water harvesting structures	0 (0)	0 (0)	0 (0)	3200 (2.3)	0 (0)
Small farmers mechanization	0 (0)	0 (0)	10,000 (1.9)	0 (0)	0 (0)

Note: Figures in parenthesis indicate percentage share of households against the total in each landholding category.

5.4. Relationship between Subsidies and Land Ownership

Benefits from subsidies and welfare programmes have an inverted 'u'-shape relationship with land ownership (Figure 4). The best fit model is a cubic relationship between land ownership and total welfare benefits, indicating that the landless benefited least. However, benefits were higher for small farmers, but for medium farmers benefits were reduced, and they spiked for large farmers. MGNREGA is the only programme that is universally accessed by the landless. Most of the poverty reduction schemes in rural India are intrinsically directed to support agriculture linked to land and associated assets such as free electricity, crop loan waivers, subsidies for seed and fertilizer, and even direct cash transfer to farmers. Although welfare and development schemes linked to land ownership increase opportunities for agricultural labourers by increasing employment opportunities and raising wage rates, they directly exclude all the landless households.

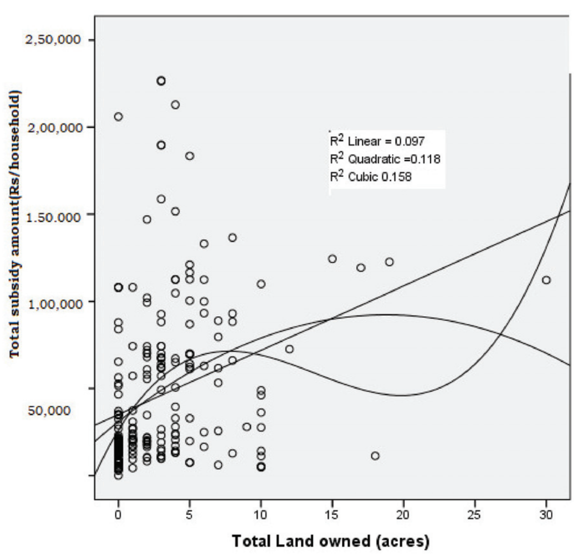

Figure 4. Relationship between land ownership and total subsidy.

5.5. Relationship between Household Income and Total Subsidy

Since landownership has a strong positive correlation with household income, we also observe an inverted 'u'-shape relationship between the total benefits received by households from welfare programmes and total household income (Figure 5). Similar observations were made in other studies [34,35]. This indicates a large exclusion error, particularly among the bottom 20% of households. In other words, schemes that are launched for rural households to reduce poverty are also being used by the non-poor households in the village, and often the actual poor are not benefiting.

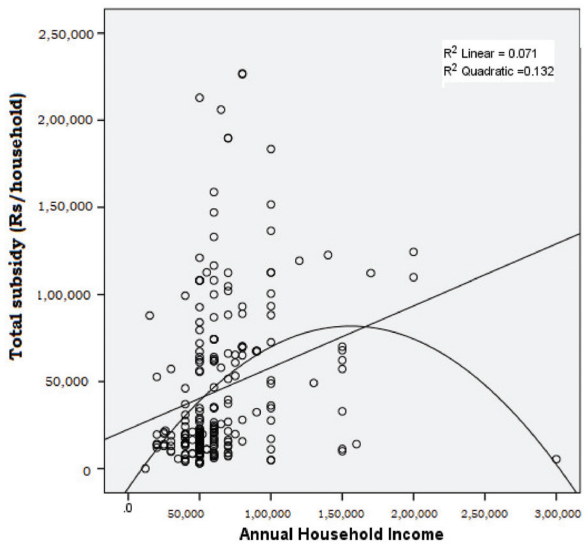

Figure 5. Relationship between household income and total subsidy.

Such exclusion errors in targeting have long-term implications. They tend to increase vertical inequality, i.e., inequality between the poor and the non-poor. Simler and Nhate [36], in their study in Mozambique, also found that geographical targeting may not benefit the poor in places that have fairly heterogeneous poverty levels. Thus, in unequal societies, the programmes that aim to benefit the poor need to be reoriented and redesigned in such a way that exclusion does not happen in its targeting.

5.6. Relationship between Benefits and Social Class of the Beneficiary

In an empirical analysis [11], Zacharias and Vakulabharanam established (as expected) that the disadvantaged groups in India known as the SC and ST have substantially lower wealth and assets than the FCs. In our study village, too, the families with large land holdings with wealth were high caste. In line with our discussion in the previous section, it is clear that the benefits from the programmes have disproportionately gone to the rich, land-owning FC households (Figure 6). FC households were getting the highest public subsidy, with INR 55,660 (USD 733), followed by the "BCs" (sic), with INR 43,160 (USD 568), and INR 37,834 (USD 500) for SCs. The average benefits were lowest among labourers, at INR 22,313 (USD 294), and also among the landless, at INR 35,826 (USD 472).

With empirical evidence of large exclusion of the poor and the socially disadvantaged groups from the welfare schemes, our study suggests that social welfare schemes benefit the socially and economically better-off households, further pushing the poor and/or SC families towards poverty. This is inevitable as poverty in India is complex, with historical roots and socio–economic inequality due to skewed ownership of landholdings in favour of high castes. As discussed in the earlier section, the farmers with large landholdings benefit more from the government programmes due to the large sums of institutional loan waivers, free electricity with tube-well ownership, and fertilizer subsidies. These benefits also increase with increased farm size.

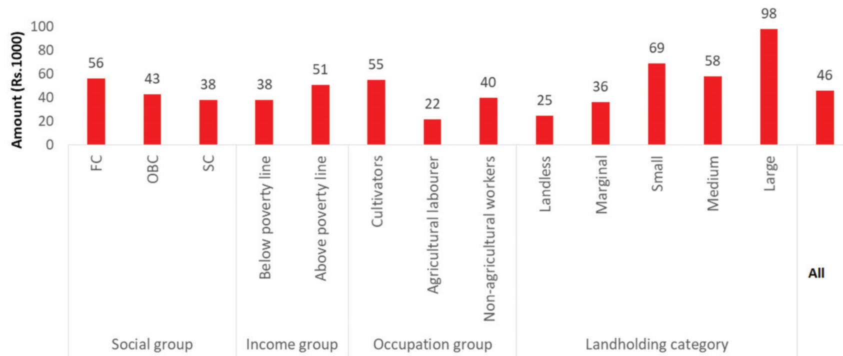

Figure 6. Benefits accruing to different beneficiary groups under different schemes.

5.7. Utilization of Benefits

Among the utilization of benefits, free electricity, the fertilizer subsidy, and soil health card schemes were accessed by all households (Figure 7). The schemes that were linked to agricultural development were inadvertently used by landowning households and did not cater to the general welfare of the poor who were landless or to agricultural labourers.

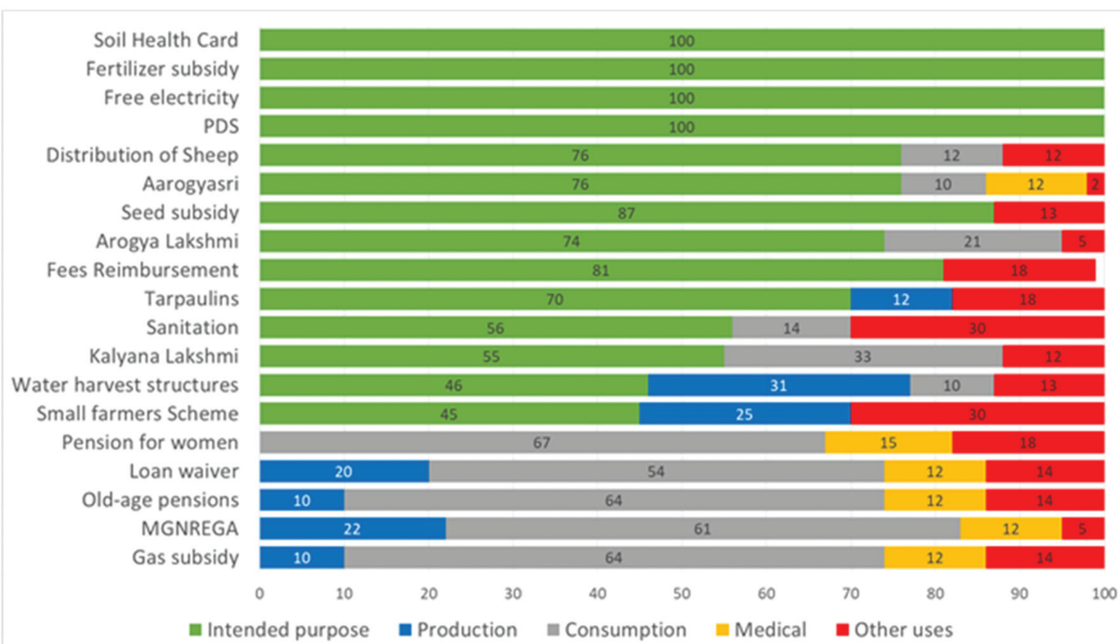

Figure 7. Utilization of programmes by purpose (% of beneficiaries).

5.8. Are the Programmes Targeting the Poorest of the Poor?

Our household survey data were divided into two income categories based on the annual income of the respondents: the bottom 20% of households are called the poorest-of-the-poor, and the other 80% are referred to as not-so-poor. Our analysis notes that the benefits accruing to the not-so-poor households are systematically higher than benefits received by the poorest-of-the-poor households (Figure 8A,B). This indicates targeting errors and loopholes in implementation.

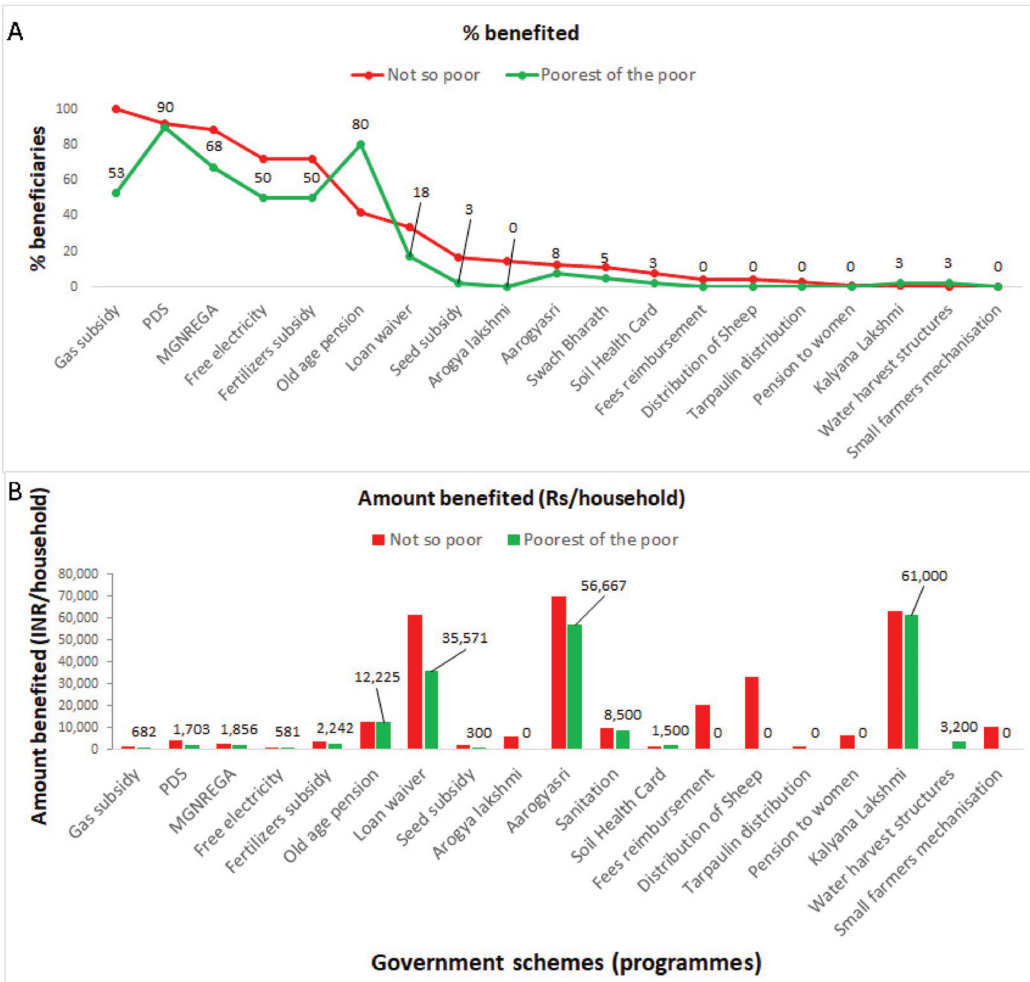

Figure 8. (**A**) Beneficiary households (% of total) covered under different schemes and (**B**) average amount.

We observed large exclusion errors or F-mistakes for "Failure to cover" in the welfare schemes in our study village. Such errors occur when targeted persons do not benefit from the very programmes meant for them [37], in this case, the "poorest of the poor". Most of the schemes do not reach the poorest of the poor because they come with a precondition of asset ownership, which the poorest do not have due to their poverty. Thus, the programmes often fail to target, leading to exclusion errors. Table 4 summarises the targeting errors and their reasons for each programme.

Table 4. Targeting errors and gender priority of development and welfare programmes in the study village and their reasons.

Programmes	Description	Type of Targeting	Targeting Errors	Reasons for Poor Targeting of Beneficiaries	Gender Rating (Min = 0; Max = −5)
Gas subsidy (cooking)	To provide 12 subsidized LPG cylinders per year to households	Universal targeting	Large inclusion error	This universal scheme benefits all, but the poorest of the poor are deprived due to their inability to purchase gas stoves.	5
PDS (Public Distribution System)	The Indian food security system to distribute food grains (mainly rice and wheat) to India's poor at subsidised rates	Targeted to below-poverty-line households	Large exclusion and inclusion error	No proper income estimations	3
MGNREGA	To guarantee 100 days of employment for every household per year through arranging public works in the vicinity of the village	Self-targeted workfare	Small exclusion error	Due to sickness and physical disability, some poorest of the poor are not able to work.	5
Free electricity	Free electricity for irrigation to run motors of pump sets for agriculture	Targeted to farmers with bore well and electricity connection	Large exclusion error	Only accessible to rich, landowning households having tube-wells connected with electric motors.	0
Fertiliser subsidy	To make fertiliser application affordable to farmers to increase yields	Targeted to farmers who use fertilisers	Exclusion error	Farmers with large landholdings and access to irrigation buy more of these fertilizers, while small landholders get little benefit and landless labourers do not get any subsidy	0
Old age pension	Aasara pensions (old age pension): A type of pension provided to elderly, disabled, widows, elderly weavers, and other informal sector workers	Demographic targeting	Exclusion error	Some elderly do not get pensions due to lack of supporting documents such as proof of age or residence certificate	3
Loan waiver scheme	To waive crop loans taken from formal financial institutions (scheduled commercial banks) up to 1 lakh	Targets farmers taking loans from formal sources such as banks	Exclusion error	Poor farmers without collateral who take loans from informal sources and tenant farmers get excluded.	0
Subsidy on seed	To supply quality, improved, and certified seed to farmers at 50% subsidy	Targeted to farmers who buy seed from government sources	Large exclusion error	Only paddy farmers who purchase seed from the government are getting seed subsidy. All private seed is without seed subsidy.	1

Table 4. *Cont.*

Programmes	Description	Type of Targeting	Targeting Errors	Reasons for Poor Targeting of Beneficiaries	Gender Rating (Min = 0; Max = −5)
Aarogra Lakshmi	Aarogya Lakshmi is a nutritional program to support pregnant and lactating women. The scheme is available for women below and above poverty line	Pregnant and lactating women	Some exclusion error	Some pregnant women are not enrolled in the scheme	5
Aarogyasri	To cover the health expenses of the poor in case of hospitalization	Targeted to in-house hospitalisation	Large exclusion error	Restricted only to hospitalised people.	3
Swach Bharat	To maintain cleanliness and eradicate open defecation, government subsidies for construction of toilets in their houses for poor households	Universal targeting	Some exclusion error	Only households with own house are eligible for subsidy	5
Soil Health Card (SHC)	Although farmers are aware of the SHC scheme, until now farmers of the village did not have the SHCs. As the villages are remote and affected by Maoist movement, agricultural officers are reluctant to go to the villages to collect soil samples.	Universal targeting of all farmers	Large exclusion error	Many farmers have not received the SHCs	2
Fee reimbursement	To provide scholarships to the students of economically weaker sections pursuing higher education	Targeted to cover higher education fees of below-poverty-line households	Exclusion error	Due to poor educational facility in the village, poor children drop out after primary schooling. Only high-caste rich people can afford to enrol their children in higher education.	2
Distribution of sheep on subsidy	To provide traditional shepherd families 20 + 1 sheep on 75% subsidy for their development to increase livelihoods from livestock rearing	Targeted to shepherds	Exclusion and inclusion error	Does not cover all households due to limited budget and also no distribution of sheep to non-shepherds.	3
Tarpaulin (under Rashtriya Krishi Vikas Yojana: RKVY)	Tarpaulins are distributed to farmers for covering grain from rains, use as drying platforms, used for cleaning and grading of grains after harvest.	All small holding farmers	Balanced	Only small fee is required for each tarpaulin, hence most farmers benefited.	2

Table 4. *Cont.*

Programmes	Description	Type of Targeting	Targeting Errors	Reasons for Poor Targeting of Beneficiaries	Gender Rating (Min = 0; Max = −5)
Abhayahastam	SHG women contribute INR 365 per annum and government co-contribution of INR 365 per annum into pension account. Interest is earned on the principal to age 60 years, then is paid out as monthly pension	All women Self-Help Group (SHG) members are targeted group	Non-SHG members are excluded.	Many non-SHG women are not covered	5
Kalyana Lakshmi	Help girl's families with financial assistance of INR 75,000 to cover marriage expenses.	All households with girls age above 18 years are covered	No inclusion or exclusion error		5
Water harvesting structures	Subsidies for construction of rainwater harvesting structures on farmland	Targeted to all farmers	Exclusion error	Only a few farmers with large landholdings benefit	3
Small farmers scheme	Assistance to small landholding farmers to purchase small inputs such as plough and sickle	Targeted to small farmers	Exclusion error	Due to limited budget allocation, very few benefit	3

Note: Gender rating 1–5 scale is developed to understand gender focus of different schemes: 1 = no focus on women, 2 = less focus, 3 = medium focus, 4 = more focus; 5 = 100% focus.

It has been observed that large exclusion errors reduce programme costs but diminish impact in poverty alleviation [15]. By transferring resources to non-poor individuals, the programmes increase vertical inequality, i.e., between the poor and the non-poor [14], impeding horizontal efficiency and creating resentment and social instability [38]. Many studies have also shown that the risk of capture by local elites grows with inequality in land and asset ownership [33,39] and with resource depletion [33], particularly in programmes that intend to target poor farmers for agricultural input and credit distribution. Unfortunately, local governments in areas with the highest inequality tend to choose less-efficient targeting systems [33,40], as in societies with greater inequality, the poor have less of a voice in decision-making processes [14]. Such beneficiary selection mechanisms also tend to perpetuate local power structures and exclude certain individuals from the welfare programmes for social and ethnic reasons [41].

Exclusion error in targeting of beneficiaries is a result of other factors as well, such as lack of transparency in identification of beneficiaries, implementation of schemes and associated administrative procedures, as well as lack of manpower and/or technical capacity of government personnel at the field level for monitoring and social mobilization.

5.9. Income Inequality and Reach of Subsidies

In the village, inequality plays an important role in every life and in socio–economic relationships between households. In the village, inequality in landownership is high, further inequality in irrigated landownership is much higher, but income inequality is less. This is mainly due to non-land-based incomes, such as casual labourer, nonfarm and off-farm employment, business, and self-employment opportunities, in villages have increased over the past two decades. The reach of subsidies such as gas and food subsidies is more equal among village society, as they are not based on assets (particularly land); however, some land-based subsidies, such as credit subsidies and agricultural input subsidies, such as fertilizer subsidy, are highly skewed (Figures 8 and 9).

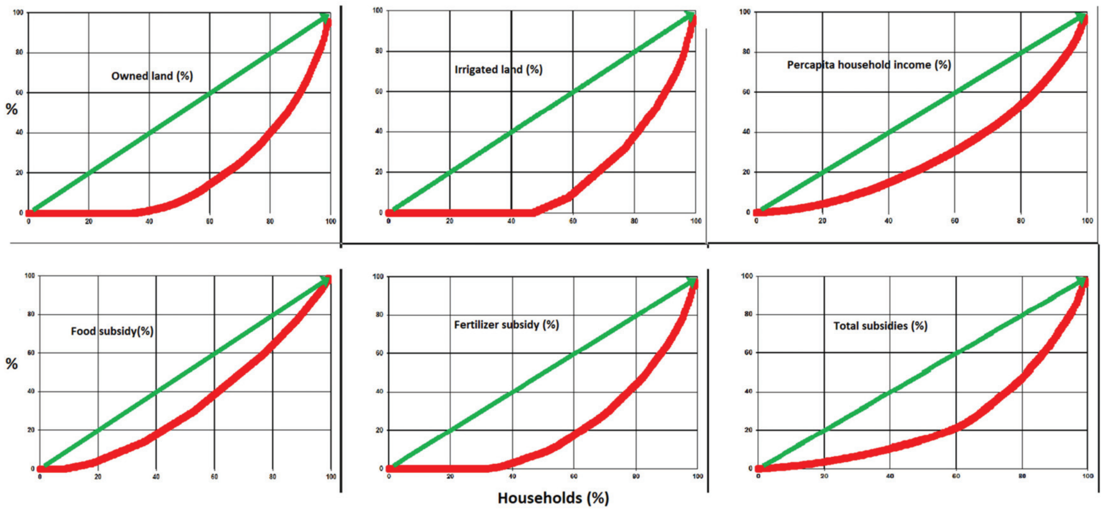

Figure 9. Lorenz curve for landownership, irrigated area, per capita income, food, fertilizer, and total subsidy.

5.10. COVID-19 Shock and Agility of Government Schemes during Pandemic

India reported its first COVID-19 case in March 2020, and there were three waves between 2020 and 2022 (Figure 10). All countries pumped a lot of money towards social safety nets to protect households from job losses and for income opportunities, including India. COVID-19 is the test case for understanding the agility of government schemes towards external shocks through various social safety nets. With the increased focus on direct money transfer since 2013, the systems from top to bottom are all strengthened to transact huge sums of money. As part of overall measures to increase transparency, the government also promoted direct benefit transfer (DBT) in all government schemes (Figure 11). In 2022, some 420 schemes are working in DBT to reach beneficiaries. The DBTs were facilitated by Pradhan Mantri Jan Dhan Yojana (the Prime Minister's People's Wealth Scheme), which is a financial inclusion program of the government of India open to Indian citizens that aims to expand affordable access to financial services such as bank accounts, remittances, credit, insurance, and pensions. Under this scheme, almost all households have Jan Dhan bank accounts, including the poorest of the poor in India. Further, DBTs are accelerated by the Jan Dhan–Aadhaar–Mobile (JAM) trinity, which refers to the government of India's initiative to link Jan Dhan bank accounts, mobile numbers, and Aadhaar cards (national unique identity card) of Indians to target beneficiaries and plug the leakages of government benefits.

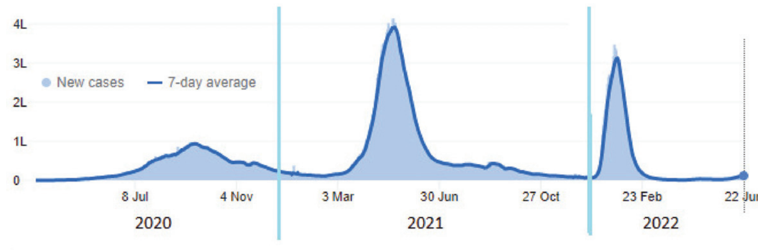

Figure 10. Corona cases in India from 2020 to 2022. Source: https://github.com/CSSEGISandData/COVID-19 (accessed on 20 June 2022).

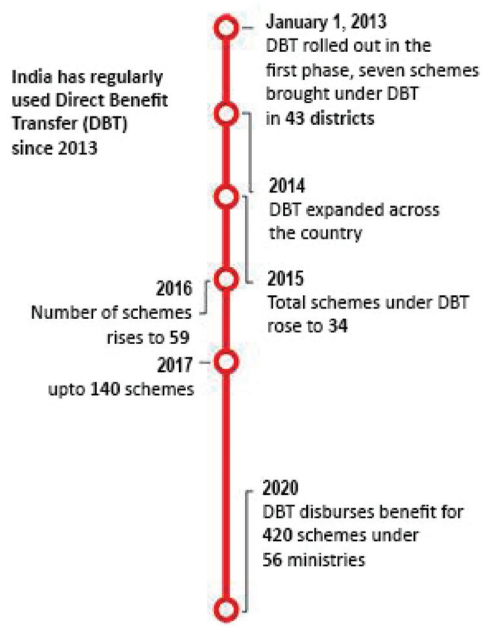

Figure 11. Progress of Direct Benefit Transfers (DBTs) in India. Source: https://www.nic.in/blogs/direct-benefit-transfer-a-blessing-during-the-time-of-pandemic/ (accessed on 20 June 2022).

Figure 12 shows the number of beneficiaries under DBT in millions under different schemes for financial years 2016–2017 and 2021–2022. The years 2020–2021 and 2021–2022 fully reflect the additional direct money transfers due to the COVID-19 pandemic outbreak. If we compare the COVID-19 year 2020–2021 with the normal year 2018–2019, there is a huge jump in the number of beneficiaries in the PDS as the government pumped in more free food grains to ensure food security to all households, including migrants. There is also a huge increase in the employment guarantee programme (MGNREGA), as many casual labourer who lost employment in urban areas returned to villages and engaged in MGNREGA public works.

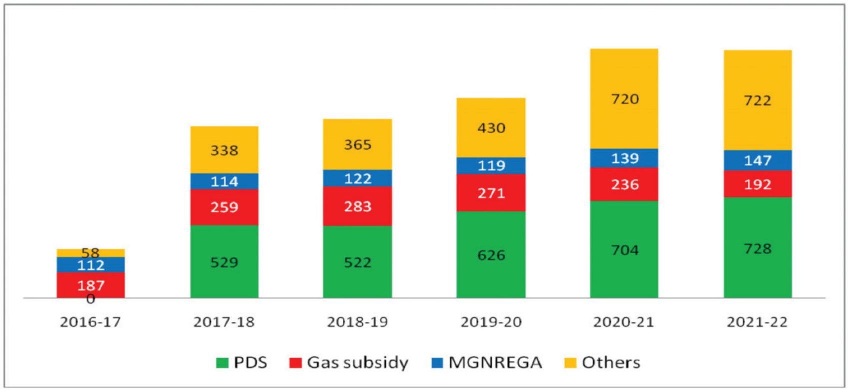

Figure 12. DBT beneficiaries under different schemes (million). Source: https://dbtbharat.gov.in/ (accessed on 20 June 2022).

Figure 13 depicts the amount of money transferred through DBT pre- and post-COVID. There is again a huge increase, particularly in PDS, MGNREGA, and even the fertilizer subsidy, as global fertilizer prices increased. In order to compensate for this, the government hugely subsidised fertilizers.

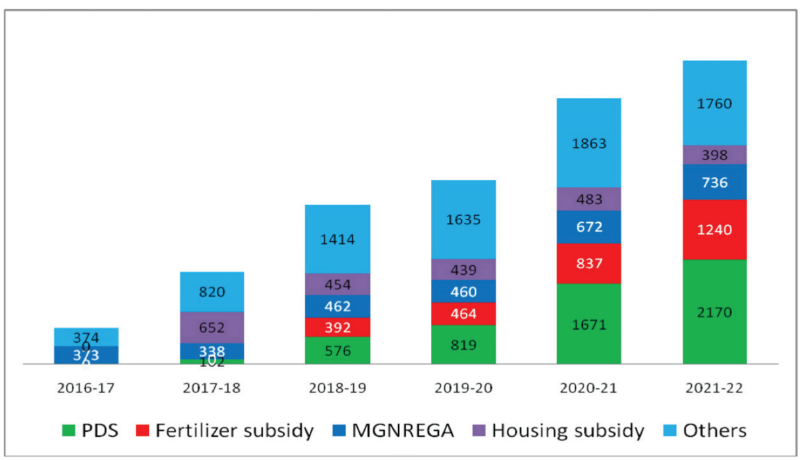

Figure 13. Direct benefit transfer (in billions of rupees in cash or kind) through DBT under different schemes in India. Source: https://dbtbharat.gov.in/ (accessed on 22 June 2022).

Overall, there was a huge increase in government support during the COVID-19 pandemic shock, especially in rural areas. The same is reflected in focus group discussions during the COVID-19 period among the households in the study villages.

6. Conclusions

Poverty is pervasive in India. However, poverty is mostly concentrated in particular social groups and also in rural areas, where the majority of households depend on agriculture. It has become a social phenomenon where a particular section of society or a social group is unable to fulfil their basic necessities for life [42]. This study intensively examined the reach of various government welfare and development schemes among the poor, socially disadvantageous groups of a population in a village in India by selecting a representative village in the Telangana State. The data were collected by using mixed methods, with primary data collection from all households along with focus group interactions to understand the dynamics of the functioning and reach of social safety net benefits. All households living in the village were surveyed in order to guarantee inclusion of the poorest of the poor and socially disadvantaged groups so that their opinions will get due representation in the sample. We observed that some universal social safety net programmes such as MGNREGA, PDS, the gas subsidy, and the midday meal scheme benefit the majority of the population, while others benefit the rich more than the poor despite targeting the poor [43]. Our study also had similar findings. The results show an inverted 'u'-shape relationship between total benefits received by households from welfare programmes and household income and land ownership. Hence, there is a need to step up access to welfare schemes for the bottom 20% of households with more-efficient targeting methods.

The eligibility criteria and targeting mechanism employed for identifying beneficiaries under the schemes have significant influence on who will benefit from the scheme. Most of the schemes in our study village targeting rural populations had a prerequisite for asset ownership, such as land. Thus, large landowners who had large institutional loans benefitted from loan waivers and were also irrigating their crops with free electricity and buying subsidised fertilizers. Even the poorest did not benefit from the gas cylinder subsidy as they did not have a gas oven and were still dependent on fireweed for fuel. Without collateral, the poor people had to depend on informal loans and borrowing, thus were not able to benefit from the government loan waiver. Without a secondary school in the village, the poorest were also unable to enrol their children in secondary education and hence were disqualified for the higher education welfare programmes.

It is evident that the success of targeted poverty schemes in India is dependent on proper identification of beneficiaries, transparency, supervision over field staff, and social mobilization. In the past, the central government has allocated fewer resources to villages and regions where poverty, inequality, and the proportion of low-caste individuals are high [39]. Though funds have more than tripled in the last ten years for poorer districts, it is questionable whether there is sufficient capacity at the district and sub-district levels to absorb the funds and produce quality results with existing capacity. Given that some schemes require a lot of procedures and documentation and coordination among various departments, many illiterate households are unable to take benefits even if they qualify for such programmes. Without assessment of existing capacity and in absence of strengthening the very agencies at the field level who have to take on the massive task of delivering a number of schemes, many welfare schemes take off far slower than intended, and often end up being implemented in a haphazard manner—this also includes inappropriate targeting of beneficiaries. This calls for simpler and universal minimum income support for every poor household living in a rural area [44]. Moreover, good governance is the key to successful implementation, and local governments should be incentivised to improve their performance in this regard. The importance of government welfare and social safety net schemes further increase during external shocks such as the COVID-19 pandemic in order to alleviate pain of loss of employment and to increase food security.

However, this paper did not do an intensive field survey post-COVID-19 to understand the actual benefits received by the poorest of the poor during the COVID-19 period. Future studies can focus on dynamics of reach of these social safety and welfare schemes to the bottom 20% of households, especially during external shocks such as pandemic or conflict.

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