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Land, Innovation and Social Good 2.0

Edited by
Kwabena Asiama, Rohan Bennett, Winrich Voss and John Bugri

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Guest Editors

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Preface

The increasing awareness of societal and global challenges has triggered a new wave of technological innovation in the administration of land. The link between the administration of land tenure, value, use, and development and the achievement of global challenges has shown the need to align the societal needs to the expanding land administration toolbox. The adaption of volunteered geographic data capture techniques, imagery-based mapping approaches, and cloud storage options to land administration have provided an increasingly cheap and fast way to collect land information. However, a range of newer innovations with big data capture feeding into artificial intelligence has created even more avenues for automatic parcel boundary extraction, automated valuation models, as well as spatial decision support systems for smart cities and settlements.

Running counter to these innovations are the societal challenges, such as rapid urbanization, food insecurity, climate change, disaster risk management, and gender inequality, faced around the globe. This Special Issue sits at the nexus of how technological innovations in land administration can contribute to the achievement of the global challenges of our day.

In this Special Issue, eight original articles and two reviews, submitted by multidisciplinary teams, on the linkages between land, technological innovations and their contribution to societal and global challenges, have been collected. The articles have a global geographic span, with papers from Europe (Germany and Greece), Africa (Niger and Ethiopia), Asia (China), and North America (USA).

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Guest Editors

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Article

Social Aspects in Land Consolidation Processes

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Abstract: Land consolidation is an instrument that readjusts land parcel shapes and reallocates land rights in order to minimize farmland fragmentation, optimize agricultural output, and generate optimal living and working conditions in rural areas. The optimization and reallocation algorithms typically rely on monetarized values of land parcels, soil quality, and compensation amounts. Yet, land management interventions also need instruments for socio-spatial optimization, which may be in conflict with the monetary ones. Many non-monetary values are qualitative in nature. Hence, there is a research gap in how such values can be detected and incorporated, such that they can create a multi-dimensional land consolidation outcome. This study applies a situational analytical approach to investigate how, where, and when social values and belief systems play a role in land consolidation cases in three different study areas. This process enables the qualitative detection of which types of social values are central during land consolidations and which ones are most essential when evaluating outcomes of land consolidation. The synthesis derives that the incorporation of aims—such as addressing socio-spatial affinity, need for equity and fairness, human recognition, and good neighborship—is possible through an innovation in land consolidation practices, social valuation methods, and/or socially responsive land consolidation laws.

Keywords: land consolidation; land management; land readjustment; social values; rural development; social valuation

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1. Introduction

Land consolidation is a land management instrument, which intervenes in existing land parcel and land right structures in order to improve the effectiveness of land use and de-fragmentize existing land rights. Practically, this usually involves land-adjustment and land re-allocation processes, aligning the interests of participating land right holders and optimizing parcel shapes and supporting infrastructures. There are multiple variations in how to execute such a process. Various international comparative studies [1–5] demonstrate these global variations in types of participation (legally versus voluntary involvement), types of spatial changes (farmland restructuring versus road and infrastructure construction), or types of rights re-allocation (ownership rights versus use rights). Regardless of the particular land consolidation type, both land consolidation planners and facilitators as well as different land consolidation software types employ specific optimization procedures and algorithms in order to create a land consolidation plan which is better, more advantageous, and more acceptable for all participating stakeholders than the existing situation. The back-up position is hereby that when any participant does not sufficiently benefit for these improvements, a compensation for this loss or unequal benefit is allocated. However, the optimization process requires a particular choice regarding the optimization perspectives, goals, criteria, thresholds, and comparative advantages or disadvantages. In other words, the optimization is not value-free as some, if not all, of such choices depend on how legislators and practitioners have shaped the legislation and the operationalization through their preferences, professional discretions, social agency, powering and brokering influence, and de facto social behavior. Such a practice embeds the epistemic and axiological choices of the underlying land consolidation acts and practitioners, and thus—by default—neglects or even rules out alternative values and belief systems on what might be optimal. Given this, it is necessary to examine these choices critically and to evaluate which alternatives might have possible advantages or benefits. Therefore, the objective of this article is to investigate how, where, and when social values and belief systems play a role in land consolidation.

This investigation starts from the criticism that land consolidation is not always solving the socio-spatial problems that it was supposed to address [6]. On the one hand, various studies indeed praise the instrument because it has a clear advantage of addressing spatial and legal fragmentation as opposed to, for example, land expropriation [7], has a long-lasting effect on slowing down land abandonments, and fosters technological innovations in optimizing land [8]. However, overall, a large share of evaluative and reflective studies on land consolidation overemphasize the positive effects [9] and disregard the negative sides, which are predominantly ideological, social, societal, administrative, and political. Firstly, as a solution to a problem, the problem framing and definition may be questionable [10]. Farmland fragmentation may not be the real problem or challenge for farmers, citizens, or village society, and it may actually be a reasonable and economic solution to farmland risks, for example [11]. The agricultural efficiency gains may actually lead to loss of ecosystems and in the long run derive depletion of soils and thus significant loss of agricultural benefits [12]. The emphasis of economic narratives may contradict the interests of paradigms of the territorial emancipation, visions of land for the commons, and respect for nature [13]. Last but not least, complex administrative systems may hamper or even completely neglect interests of stakeholders [14], resulting in long, bureaucratic, and technocratic solutions. In other words, the societal problems or the view on the problems, which the land consolidation was supposed to address, may have changed during the time that land consolidators debated or executed the land consolidation plan.

Thus, there is a need to include social and societal values in land consolidation rules, processes, and outcomes. Although land consolidation projects ultimately aim to deliver social and societal benefits, the manner in which one can achieve or measure these aims remains unknown. The main aim of this paper is not to debate or deny the relevance of optimizing economic, legal, and spatial (geometric/geodetic/geographic) aspects. Yet, with the start of a discourse on how to frame, measure, and include social and human aspects into the land consolidation concourse, one can eventually boost the significance of the social values systems when starting and executing land consolidation projects. This research is a continuation of previous research on social issues in land management. Earlier publications address the need and type of social values, and they specify a number of these for land management in general and for land consolidation in particular. de Vries [15] introduces the concept of consolidation of memory and identity. de Vries and Voß [16] compare social values to economic values in land management. Maduekwe and de Vries [17] connect human recognition to land management processes. de Vries [18] derives seven human values in land consolidation processes, and de Vries [19] distinguishes between socio-organizational values in administrative duties and responsibilities, values connected to services to citizens, and socially oriented norms and beliefs. This paper extends the previous research in the specific empirical design on how to identify and interpret social values before, during, and after land consolidation processes.

The first step of this paper is to describe the prevailing optimization rationalities in land consolidation and to induce the effects thereof. This includes a first take at where which type of social values appeared. The next section describes how the study compiled, compared, and synthesized a selection of documented evidence on the role and need for social values in specific land consolidation cases. A subsequent 'Results and Discussion' section categorizes and classifies relevant and significant social values and social value measuring mechanisms. The last conclusion section derivers the implications of the synthesis in terms of the significance of social values, alternative frameworks for land consolidations, and recommendations for further research.

2. Theoretical Rationalities of Value Optimization in Land Consolidation

Optimization rationalities strongly depend on applied epistemologies or epistemic values. Asiama [20] describes in this regard that land consolidation projects draw on two prevailing rationalities of optimization in the re-allocation and readjustment processes. The first one is open market value optimization. Hereby, a land consolidation planner aims to set an equivalent market price for each land parcel and re-arranges the shape and distribution of land parcels in such a way that each participant obtains a land parcel of at least an equivalent market value. The logic hereby is that any land owner of the entire community of stakeholders in the land consolidation process would be primarily interested in gaining the highest economic and financial benefit from the intervention, as the monetary equivalent of the resulting land parcel should be higher than the previous situation. The second one concerns agricultural value, which can be roughly translated into the monetary opportunity costs when using the land as an economic production factor. At the same time, neither of these two types of these rationalities have equivalent social valuation schemes in order to optimize social priorities or social opportunities. There are some legislations, which partially address some of these concerns. For example, German land consolidation laws have been adapted in the last decades to incorporate the socio-spatial context when implementing land consolidation projects. The current land consolidation law specifically states that land consolidation should not only serve the agricultural optimization but also contribute to optimizing the local living and working conditions as a specific requirement within any land consolidation project. In this way, land consolidation is not just benefitting the interests of participating farmers but also helping the overall quality of living in the involved villages and the closely affected stakeholders in the vicinity of the area [21]. However, the law does not add specific criteria regarding how to measure such working and living conditions nor how to use these values in a non-monetarized manner in any trade-off or exchange mechanism.

From a legal perspective, FAO's legal guide on land consolidation [22] refers to the 'at least as well off principle'. This principle is not necessarily an optimization principle but rather an optimization constraint. It implies that any change should not lead to any worse situation as compared to the existing situation. However, the guide does speak about non-monetary values by stating that 'not only monetary aspects should be taken into account, but also other livelihood and intangible gains or losses' (p. 52). It goes further by stating that land consolidation should support sustainability, consultation, participation, transparency, and gender equality. Furthermore, the guide recognizes that legitimate land tenure rights, such as unregistered ownership rights, unregistered long-term leases, matrimonial rights, inheritance rights, and mortgages should be considered when executing land consolidation processes. Yet, the guide also argues that it is not the place of a land consolidation law to 'accord legal recognition to socially legitimate rights that do not enjoy legal recognition' (p. 69). In other words, formalization or recognition is not an optimization aim at itself. It is merely a by-product of the execution rather than a core principle of optimization.

Still, some specific social criteria, norms, and belief systems are addressed in land consolidation specific research. The dissertation of Hesse [23] specifically looks at social interaction and communication problems and solutions related to land consolidation. These interactions are often hampered by existing formal and informal power structures. Those who want to participate actively—both formally and informally—are often confronted with local, regional, as well as experience-typical social structures and personal dependencies. In such situations, the core principles of equality in contributing to the final goals of the project, and possibly in the final re-distribution plan, may be at stake. Despite existing laws and guidelines, the land consolidators find themselves battling with a social hierarchy and hidden power structure that may only be observable through corresponding assertive power. It is clear from this study that local politics, personal preferences, social relations, and networks play a role, and that these factors may also be crucial in the effectiveness of land consolidation. However, it remains unclear from these earlier studies and guidelines how and when do the variations in social, public, and human values influence the process and the outcome, and how land consolidation procedures can incorporate specific social values in the optimization and re-allocation procedures.

3. Theoretical Rationalities of Social Values

From a theoretical point of view, social values, norms, and belief systems are a central subject of research in sociology, public administration, and policy sciences, yet human geography, anthropology, and cultural studies also evaluate social norms, preferences, influence, and agency. In land management, social values are often reduced to lists, classifications, or ranking schemes of interests, stakes, opinions, and preferences. However, such ethnographic and strategic classifications do not sufficiently capture the underlying norms on the one hand and the social dynamics and types of interdependencies on the other hand. For the former, de Vries. [18] identifies seven human values relevant in land consolidations, which include human identity, human values, human sentiments, human recognition, human dignity, human variation, human relations, and human choices. For example, human identity is a concept from social and health sciences to describe how individuals think of themselves and how they see, perceive, interact, and respond to the broader social world [24]. These choices influence how they choose to live their life and how they see themselves in a broader social context. This identity influences social choices and preferences in all aspects of life, especially when it affects them directly. Since most land consolidation projects involve land owners and their livelihood, their choices can be directly related to this human identity. For example, human recognition is a similar yet also different concept. It is a concept to explain and measure the extent to which an individual is acknowledged by others as being a fellow human being [25]. This acknowledgement by others creates a sense of self-respect and self-esteem, and it contributes to a sense of interpersonal being. As [18] argues, all of the seven human values are interrelated yet can contribute in different ways to how land consolidation stakeholders feel they can or want to contribute and feel acknowledged and appreciated by their contributions.

To investigate social values, de Vries and Voß [16] argue that one should differentiate three types of social values:

1. Values related to administrative duties and responsibilities. These include Responsibility to the citizen in providing land-related services, Responsibility and accountability of the elected politicians to make responsible land-related decisions, Proper and efficient use of public funds to support land interventions including land readjustments, Compliance with the laws related to land readjustment, Integrity and honesty, and Facilitating the democratic will which acknowledges input and respect for all relevant stakeholders;
2. Services oriented values. These include Service to the citizen in his or her different roles (a citizen is multi-dimensional), Respect for the individual, Responsiveness, Effectiveness, Efficiency, and Transparency;
3. Socially oriented values. These include Inclusiveness, Justice, Fairness, Equality of treatment and access, Respect for the citizen, Due process, Protecting citizen privacy, Protection citizen from exploitation, Protecting citizen security, Accountability to the public, Consulting the citizen, and Impartiality.

One could argue that 'social' values exist through the generation, legitimization, and/or institutionalization through social interactions. Then, social values systems are sets of values that guide social behavior and provide agreed sets of frames for social actions.

4. Research Design and Methodology

The research design relied on the basic premise that finding and detecting social values first of all requires a constructivist starting point, which assumes that values are created and lived within a social context and are fluid and interpretable within that context. For this reason, the research had to rely on data acquisition and data analysis methods that would appreciate this starting point. Therefore, a combination of an interpretative analysis of documented cases was combined with situational analysis. The documented cases were derived from articles and reports, whereas the situational analysis was used as an analytical tool to evaluate and interpret the documented cases. The intention for the study for this paper was to select and compile documented evidence within cases, which explicitly address social aspects, and then interpret the findings in a new type of framework. Such cases do exist but are not large in number. Many articles on land consolidation tend to restrict the social issues to social problems that land consolidation can solve, instead of investigating which problems are within land consolidation itself. For example, some examples on the contrary include the publication of Thapa and Niroula [26], who refer to inequitable access in the Gajuri and Kumpur Village Development Committees (VDCs) of Dhading district in Nepal, as a direct result of reluctant and socially averse peasants during the preparation of land consolidation plans. In addition, Wang, Zhang [27] refer to different attitudes in relation to participants' occupation and age, which affect the degree of participation, flexible implementation, and adequate compensation. Lastly, the documented evidence of Hoe [28] describe for the case of the Sarawakian community of Bumiputera, Malaysia how and why principles of social justice, human rights, collective responsibility, and respect for diversities are fundamental to social work, including the work completed within or connected to land consolidation projects. However, understanding such cases requires more in-depth knowledge of the cases itself and the social context in which those behavior and social values and social principles during a land consolidation process emerged. In order to overcome this research complication, this study applied the tool of situational analysis. The analytical tool of situational analysis aids in the interpretation of where and how the incorporation of social values is meaningful, realistic, and practical. The focus in this article is on cases where direct involvement and direct acquaintance was present, in order to understand and interpret both the context and the situational dilemmas.

Situational analysis is a methodological tool to understand social worlds and social dynamics. It supports investigating complex situations whereby multiple arenas, administrative levels and authorities, and sequences of events interact [29,30]. The analytical tool draws on careful descriptions of symbolic and discursive elements in a particular context or situation. Such descriptions allow connecting documented evidence in reports, gray literature, and scientific literature to direct observations and personal first-hand experiences of project managers being involved and/or connected to specific land consolidation projects on site. Situation analysis builds upon a description through situational, social arena, and positional maps. Situational maps refer to an overview and a mapping of the inter-relations between discursive, historical, cultural, and political elements to describe a situation. Social arena maps provide an overview of actors and the way they transmit their intentions and negotiate their objectives. Positional maps portray ideas, claims, norms, or objectives. For the specific case of land consolidation, one can employ situation analysis (i.e., a combination of a situational, social arena, and positional maps) to derive an insight on:

1. (Situational maps) Which metaphors or symbols do participants and stakeholders transmit to describe their problems in their daily situation, and which social values connect to describe these?
2. (Social arena map) Which social values relate to how land consolidators communicate strategies and solutions to collected problems of current situations?
3. (Positional map) How do which embedded epistemological choices in the chosen methodologies and/or technologies to solve land consolidation problems translate into (possibly conflicting) social values?

The investigated cases included the following countries and types of land consolidation projects:

Case in Bavaria, Germany. This relied on the Bachelor thesis work and associated data acquisition of Guggemos [31], the data connected to the Bavarian survey part of the collaborative study on comparative land consolidation practices under the auspices of the Working Party for Land Administration (WPLA) and the doctoral dissertation and associated data acquisition of [23]. In Bavaria, land consolidation projects follow the land consolidation act, which explicitly states and shows that land consolidation does not just aim at defragmentation and optimization of agricultural land, but also at improvement of the living and working conditions in rural areas. Therefore, statistics on land consolidation are typically part of the rural development and village renewal statistics. The latest annual reports of the Bavarian ministry of food, agriculture, and forestry indicate that the number of state-supported land consolidation projects is gradually declining (2018:725; 2019: 720; 2020: 714), whereas the number of projects involving voluntary land exchange is increasing (2018: 195; 2019: 222; 2020: 241).

Cases in Europe. This relied on the documented results of collaborative study on comparative land consolidation practices under the auspices of the Working Party for Land Administration (WPLA), presented at conferences via [18,32,33]. This study assembled and interpreted 20 narratives, e.g., reflective stories, from experienced land consolidators on their land consolidation activities, their ideas about success and failure in land consolidation, the policy and political changes that affected land consolidation execution, and the policy windows that enabled major changes in land consolidation.

Cases in China, in particular Guangxi and Shandong provinces, were documented and interpreted via the articles [1,34] and the subsequent publications of [2,14,35]. The former refer to investigations related to the motivations and behavior of farmers during and after land consolidation and to general processes and procedures in China. The latter refer to specific projects and effects occurring after adapting the exiting land consolidation goals and ways of execution.

These three types of case study groups are relatively well documented, and details on project sizes, construction amounts, or volume of investments are given in most of these documentations. However, since the main emphasis in the paper was to detect the social values instead of the economic or agricultural ones, these details were considered less relevant for this article.

5. Results

5.1. Case Bavaria

Germany has different types of land consolidation procedures. The 'regular/standard' procedure, according to § 37 of the land consolidation law, is the most comprehensive one, as it encompasses not only an improvement of agricultural farmland optimization but usually also a considerable investment in roads, waterways, landscape, and living and working facilities. However, the statistics of land consolidation projects indicated that the rural development agencies opt increasingly less for regular land consolidation procedures. In Swabia (Schwaben), about 30% of the land consolidations are carried out as standard procedures, 35% are carried out as corporate procedures and 35% are carried out as simplified procedures. In Upper Bavaria (Oberbayern), about 50% of the procedures in the area of land consolidation are pure land, 36% are village and field procedures, and 14% are voluntary land swaps. The simplified procedures are gradually becoming the most preferred option. This is a relevant issue for the situational mapping. Simplification is a frame to opt for the faster alternative, with the perception that the objectives of such land consolidation processes are more concrete. Additionally, such projects are perceived as being more transparent, given a smaller group of participants. It is indeed true that such simplified procedural land consolidation projects cover smaller areas as compared to the past (approximately 180 ha on average as compared to the 2000/3000 ha projects of the past). However, this simplified approach does follow an equivalent procedure with equivalent optimization schemes. In other words, the value systems to optimize do not significantly differ. Instead, such procedures are preferred because of another set of social values, which is adjacency, knowledge and personal acquaintance of neighboring stakeholders, and better assessment of perceived equivalent value of land and perceived lower involvement of governmental rules. This would also explain the increase in voluntary land swaps, for example, which only involve the exchange of individual plots of land.

In terms of the social arena, in which communication plays a major role, there are both formal and informal channels. In order to inform stakeholders about an upcoming procedure, the agencies of rural development sent an information letter before the land consolidation plan is issued. This lets stakeholders and in particular the involved municipalities and other government agencies know that a procedure is planned in a certain area and at the same time asks them to let you know if they have plans there themselves. For example, if nature conservation organizations know that there is a sensitive area, it is possible to react before the order is issued, for example by adapting the boundaries of the land consolidation area, such that certain plots may not be affected. Practically, a lot of the communication means are used, such as information letters, which are sent out when surveying work is scheduled, for example, so that the owners know what is happening on their property; additionally, some of the rural development agencies open a (data) cloud for all public agencies displaying the maps and the plans. In addition, there is always the possibility to discuss open questions in a personal conversation with an employee of the rural development agencies. In case of smaller communities of participants, information is often passed on to other participants via the board members: for example, with a telephone call or a personal conversation. Owners also receive information during a land consolidation process on the status of their rights and obligations, even before the final allocation, and there is even the possibility of having a one-on-one meeting. During the final meeting, the stakeholders discuss the land consolidation plan such that all can identify or associate with their respective new situations and new legal statuses. As all receive an extract from the land consolidation plan relevant for their own plots, they can directly react to whether they agree with the final allocation or not.

The formal regulations are supplemented by informal instruments. These include participatory methods, question and feedback opportunities, and opportunities to personally participate in land consolidation project management. Essentially, one could argue that communication and interaction opportunities are perhaps too broad in Bavaria. There is much more participation and information distribution throughout the entire process than is actually required by law. The only requirement by § 5 of the land consolidation law is having an information meeting at the beginning of the procedure. However, there are usually many more meetings during the entire procedure. Furthermore, all citizens have the opportunity to participate in site inspections, site meetings, a field workshop, and additional meetings; all citizens have the opportunity to inform themselves in detail about the procedure and to participate. In addition, the offices for rural development already extensively discuss concerns, possibilities, and limitations within the land consolidation project during the preparatory phase. The discussion partners in such projects are amongst others water management bodies, nature conservation organizations, and road nature conservation or road construction agencies. Such early discussions help to prevent and mitigate possible bottlenecks and disagreements at an early stage. This reflects on the one hand an extreme significance of transparency (i.e., working without any secrets or hidden agendas for any stakeholders) and openness (i.e., complete and accessible documentation of all steps, decisions, and responsibilities) as core values, but perhaps also an extreme prominence of risk avoidance for government agencies or strong devolution of responsibilities and accountabilities.

The positional map, on the epistemological embedding in choices, can be inferred from the type of problems for which land consolidation is considered a solution. The Bavarian narratives in the WPLA study framed various problems. A narrative excerpt was: *The starting situation was insufficient agricultural roads, uncontrolled surface water running off, characterized by a large fragmentation of land tenure, attractive meeting point for young people and no attractive village square.* This statement reflects that land consolidation is needed because of spatial development problems and hence requires integrated development solutions. Hence, land consolidation is approached with a spatial, or territorial, development epistemology which is broader than a purely economic issue. Furthermore, a second excerpt reflects a demographic issue, which influences the execution of land consolidation:
Especially many experienced employees left our office and found new occupations partly in quite another professional field. Because the relocation took place nine years we lost more than half of our

staff. You can imagine what that means concerning our competence and skills. We had to establish nearly a complete new staff. We have not finished yet.

This excerpt demonstrates that organizational capacities and demographic skewness as a direct consequence of aging problems at the regional offices are inherently influencing the quality of the execution of the processes. Such demographic skewness may ultimately also influence the way certain preferences and belief systems are interpreted by land consolidators and may give rise to age inequalities or a lack of understanding for interests of youth. Consequently, also certain supporting technologies may be neglected in such processes.

5.2. Cases Europe

In the evaluation of narratives of senior land consolidators in 20 different European countries, there were both similarities and differences between the countries. The 20 countries included Austria, Azerbaijan, Germany, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Hungary, Lithuania, Northern Macedonia, Netherlands, Norway, Romania, Slovenia, Slovak Republic, Spain, Sweden, and Ukraine. A common element among many countries was that fragmentation, and associated fragmentation indices, are still dominant in the land consolidation discourses. This is clearly visible in a statement such as '*Some farmers possessed 30–40 land plots as a result of land commerce, lease and inheritance*' or '*The fragmentation of land parcels occurred after the implementation of land restitution (reform) when the land was returned back to its former owners, their children or grandchildren*'. Most of these land consolidators also judged fragmentation as a permanent phenomenon, because inheritance combined with new investment and land interventions would continue to take place. Thus, one could even ask if the fragmentation of land is really the key problem (such as the article [11] posits) or whether socio-temporal diversification is the real problem. What also occurred in many of stories of land consolidators was the perception that the multi-dimensional aims and contradictions, in land consolidation projects (i.e., having to aim for integrated or multiple spatial, ecological, and economical objectives) have become a clear challenge for both stakeholders and consolidators. This led to a call for more simplicity in the execution of de-fragmentation and organizational set-up in the Bavarian cases but also to a certain degree of internal resistance and inertia in many eastern European countries. Obviously, in western Europe, there has been more time to adapt and adopt as compared to eastern Europe, and there may also be a dominant mindset of resistance of farmers or stakeholders to accept new rules and conditions (reflected by a statement such as '*farmers, scared of many unpleasant things that have happened to them in the past, find it hard to believe in such new processes*'). Therefore, key metaphors of problems in executing land consolidation are having to deal with a dominant social belief system of the return of the dominant State and the optimization of the State's interests. What works in such cases is to avoid using land consolidation as a term or intervention policy and focus on issues of development and development facilitation. So, social complexity and social interdependency are relevant aspects to consider, whilst the state—citizen relationship is a central issue that land consolidation touches through its execution and which land consolidators could potentially optimize or deteriorate by their actions.

Regarding the social arena map, the narratives of land consolidators discovered a large variety in which stakeholders interacted with each other. The following excerpts demonstrate this variety:

- *We realized the project in only 9 months via the so-called sketch&match method in which farmers and owners make themselves the re-allotment plan during 2–3 working sessions of each one-day*.
- *Then I was asked to give a lecture about land consolidations to farmers in the municipality*
- *We summarize the context of each farmer and farm, the preferences and the areas that the owner offers to sell and purchase. In this way, the negotiation on land consolidation performs the function of informing each farmer/owner/person of exactly what the rules of the game [are],*

preparing the person and family for the approaching project and the life after the project, and in particular, for the expropriation event, that can be quite an intense experience.

- *Rural Development means constant change and adaption to new challenges. But the basic principles and our core competence are still the same: Citizen participation—always the main focus; The Community of Participants (CoP)—lived subsidiarity*

What these experts reveal is that social equality, reciprocal respect, and human recognition are crucial social values that emerge especially in the execution of the land consolidation planning. One could even go as far as stating that here also an optimization process takes place, namely one of social balancing.

The positional map equally shows a variety among countries. One can see how each is seeking pragmatic and politically feasible policy windows within which land consolidators can operate, such as:

- Concurrence with similar other policy objectives, such as new (integrated) rural development, and the formation or protection of recreational areas in a municipality.
- The start and increase of 'voluntary' (bottom–up) activities, incl. voluntary land consolidation projects, is fostered by both a rejection to state intervention, possible changes in land relate legislations and land reforms, and the occurrence of land scandals.
- Budget limitations limit the amount of projects that land consolidators can do and thus automatically lead to a priority ranking. Hereby, societal and political priorities are leading at the expense of pure agronomical or economic ones.

The window-seeking behavior implies that political feasibility and support, societal embedding, policy concurrence, and pragmatism are important epistemic and axiological values during the execution of land consolidation.

5.3. Cases China

The research of [34] writes extensively about the motivations of rural farmers in land consolidation projects. It starts from the argument that so far, the research on land consolidation in China has been too much focused on obtaining economic advantages and that little is known about social dynamics occurring before and after land consolidation projects. The rationale and considerations of farmers are often simplified to a single perspective, namely whether a farmer participates or not, whereas in reality, this question is multi-dimensional for many stakeholders. This multi-dimensionality does not only include economic opportunities and benefits but also future access to social securities and social network abilities to perform after a land consolidation process.

The work of [35] refers to a specific project example as a success story, namely the Nan Zhang Lou. It is a national pilot project of land readjustment and land development after the opening of China. Contrary to other conventional Chinese land consolidation projects, it resulted in an increase in the number of inhabitants (from 3800 at beginning to 4200 as the end), a continuous growth of the per capita income, lower costs of living, and a diversification of job opportunities through accompanying qualification measures and vocational training. Furthermore, it enabled employment in (new) village-owned businesses. In other words, the projects differed by a number of complementary aims, which were not primarily economic growth and opportunities but also creating sustainable social structures and motivations. According to [14], the choice to consolidate land consolidation is motivated by three factors. It is first difficult to maintain large amounts of subsidies for investments in rural areas such as Shandong. Secondly, changing landscapes may significantly alter the rural identity in rural areas. Thirdly, there is still a lack of a real land market in rural areas. They also argue that the solution to these problems lies in protecting people's livelihood, public facilities, farmland, and rural environmental conditions in order to improve human–land relationships instead of focusing on land as a tool to gain revenue by removing villagers without respecting their willingness and request. This implies for the situational analysis that village renewal, quality of life, integrated rural development, spatial equity (i.e., evidence of similar and equal conditions of access to land and resources regardless of the location or administrative territory), and enhancing rural identity and the willingness or motivation to remain active in rural areas become additional optimization values for land consolidation decisions.

Regarding the social area map, Jiang et al. [2] notes that the communication and interaction related to the land consolidation in China is still quite different from that in Europe. In the planning stage, planners make a first independent inventory based on their interactions with stakeholders and local government and then define the goals, tasks, and requirements and formulate the overall layout of the project. The planners test the plans with experts and stakeholders who are invited and may adjust if considered necessary. The time to inspect the plans differs per region. For example, it is 15 days in Shandong and 30 days in Zhejiang. Superior departments, such as the municipal land department, have to ultimately approve the plan. In other words, despite the possibilities for stakeholders to provide their opinions, the overall perception is that it is still a rather hierarchical administrative process. Jiang et al. [2] note for this reason that '*Unlike public participation in European LC, stakeholders, especially farmers, in China are rarely involved in the entire process. The social status of Chinese farmers in LC is not as high as that of European farmers, although it is rising*.' A notable exception to this practice is the model called "Villagers' Construction" (cun min zi jian), whereby *rural collective economic organizations or villager committees are encouraged, with guidance, to be a responsible partner of the project construction, and villagers are encouraged to participate in project construction.* The embedded social values in these types of land consolidation processes are social cohesion, social stability, and social alignment.

As a solution for the land consolidation process, Zhang et al. [34] suggests to employ a broader spectrum of policy strategies to implement land consolidation in a more multi-dimensional way. For example, this would include enhanced education and social marketing to encourage land consolidation as an instrument and provide more legal and social security during and after land consolidation processes. Additionally, the research suggests that including a more self-organizing practice of land consolidation, whereby the process follows a more facilitating role, and whereby villagers can express and exchange their ideas and wishes through forums, to a consolidation plan is likely to lead to more effective and sustainable land consolidation projects. However, this is a fundamental change in epistemological choice, from output efficiency gains changing toward outcome efficiency gains. In view of the positional map, this change is significant.

6. Discussion

Table 1 presents the results following the coding and interpretation of the cases according to the dimensions of the situational analysis.

Table 1. Situational analysis of land consolidation cases.

Type of Map	Bavaria	Europe	China
situational	Adjacency; Knowledge and personal acquaintance of neighboring stakeholders; Perceived equivalent value of land; Lower involvement of governmental rules	(de-)Fragmentation; State–citizen relationship; social complexity; Optimization of development facilitation	Village renewal; Quality of life; Integrated rural development; Spatial equity; Enhancing rural identity
social arena	Transparency; Openness; Risk avoidance; Accountability devolution	Reciprocal respect; Human recognition; Social balancing	Social cohesion; Social stability; Social alignment
positional	Territorial development; Organizational capacity; Demographic skewness	Political feasibility and support; Societal embedding; Policy concurrence; Pragmatism	Change from output efficiency to outcome efficiency

It is clear from Table 1 that different types of social values are already part of land consolidation processes worldwide. There are several implications for the possibilities to include social values or to make social values more apparent or explicit in the optimization processes and methods:

1. Incorporate social values more explicitly in the execution, i.e., in each of the steps of the legal procedures of land consolidation. For example, one could do this in the way that land consolidators approach, address, and involve stakeholders in different stages of the land consolidation process, and in the way that a land consolidation plan is negotiated. If one takes the generic processes of land consolidation depicted in [2] as the basis (from proposal stage to planning stage, implementation stage, and post-implementation stage), one could argue that involving social values such as spatial equity, outcome efficiency, and incorporating rural identity in different parts of the processes could be possible in all of the process steps. For example, during a feasibility study, one could include social coherence and acceptability as a key indicator in the feasibility. In employing the planning team, one could include a social knowledge upgrade in the requirements. In the improvement of the landscape steps, one could discuss socially relevant elements in the landscape.
2. Explicitly create a social valuation process as part of the pre- and post-land consolidation exchange, replacement, and compensation values. In other words, one should not completely rely on monetary values but also include a system of social value exchange. This would have an impact in the procedures and regulations of the respective land consolidation rules, but it would not necessarily change the process and its objectives as such. However, it would require a valid and acceptable framework of social value measurement and re-allocation. Such a framework could be a combination of the core human values depicted by [18] and the examples derived via the situational analysis above. One could classify these values as intrinsic and extrinsic social values, depending on whether the qualities of the value are part of the nature of the subject or dependent on things that come from the outside instead of from the inside. Additionally, one could classify these according to subjective (depending on operant subjectivity) and objective (aligned to measurable, c.q. global indicators). Table 2 provides a first exploratory classification of the social values that would need to be included in a framework.
3. Completely change the legal frameworks of land consolidation such that social values and social value optimization are the core of land consolidation. Such a system could in fact be in line with the tendencies to incorporate land consolidation in broader spatial, regional territorial and land development, and renewal strategies. The justification for such a fundamental change could draw on broader social development and social justice aims, which address at its core existing inequities rather than existing fragmentations and inefficiencies.

Table 2. Classification of social values.

Type of Social Values	Subjective	Objective
intrinsic	human identity human sentiments human dignity socio-spatial affinity	human indicators human choices quality of life spatial equity social stability
extrinsic	human recognition human relations	demographic skewness
	human variation social complexity reciprocal respect good neighborship fairness political feasibility rural identity social cohesion	territorial development State–citizen relationship societal embedding policy concurrence pragmatism social alignment

7. Conclusions

The goal of this paper was to detect and derive which social values could complement the monetary values in land consolidations and how and where such social values could be part of the land consolidation processes and outcome evaluations. Given the qualitative nature of this article, the concern was not to compare a specific number of countries or land consolidation projects but to detect social issues and social aspects of strategies in documented cases. The synthesis of cases in different parts of the world reveal a number of social values, which stakeholders and participants request and expect. For example, these include transparency and openness, reciprocal respect, societal embedding, and spatial equity. Including such values would innovate land consolidation practices, social valuation methods, and/or socially responsive land consolidation laws. However, this requires that land consolidation change both operationally and conceptually. Other than current research, which focuses on either spatial or economic benefits, this research makes a first step to extend the knowledge base on land consolidation toward socially responsive and socially enabled land consolidation.

The observed cases clearly exhibit differences. However, the aim of this article was not to derive a generic framework of social values that would be relevant for all possible institutional environments. Instead, what the differences reveal is that in all cases, the social aspects are already operational, either explicitly or implicitly. In very few of the cases, on the contrary, such aspects are included in legal regulations or rules, even though national spatial policies may in fact call for this.

Although this paper reveals the variety of social values in land consolidation, the research is not yet completed. The classification table needs further refinement, testing, and validation in an empirical setting in order to review which values are explicitly practical and significant, and which ones are more implicit. This paper has also not yet addressed a conceptual or theoretical framework, which hypothesizes on the inter-relations between certain values. This would also require a further exploration.

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Review

Fit-for-Purpose Land Administration and the Framework for Effective Land Administration: Synthesis of Contemporary Experiences

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Abstract: Despite the significant and explicit focus on the United Nations Sustainable Development Goals (SDGs), much of the world's land rights remain unrecorded and outside formal government systems. Blame is often placed on land administration processes that are considered slow, expensive, and expertise-dependent. Fit-For-Purpose Land Administration (FFPLA) has been suggested as an alternative, time and cost-effective approach. Likewise, the UN endorsed Framework for Effective Land Administration (FELA) demands attention to worldwide tenure insecurity by directly linking it to responsible land administration. Implementation of FFPLA and FELA is country-context dependent, and there are now many lessons of execution from various jurisdictions. Undertaken in 2022, this study synthesizes a review of experiences to provide a further update on the best global FFPLA implementation practices and inform approaches for future FFPLA projects. A systematic review is adopted as the research methodology, and contemporary articles from the internationally recognized land administration discourse are examined. The studies focus on FFPLA implementation practices and innovative approaches for delivering land tenure security. A checklist is developed, based on the FELA strategic pathways and the FFPLA fundamental framework principles and characteristic elements, to identify best implementation practices. Success stories across the globe show that the FFPLA characteristic elements and the FELA pathway goals are achieved through effective execution of the FFPLA framework key principles. As a result, the study identified successful FFPLA implementation practices in Asia and Africa, which can be synthesized and extended to realize tenure security in rapidly urbanizing areas. However, further study is necessary to determine the efficacy, practicability, innovativeness, and transferability of the best practices to other land administration scenarios.

Keywords: best practice; land administration; fit-for-purpose; tenure security; sustainable development; geospatial technologies

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1. Introduction

Conventional land administration systems focus on protecting land tenure security and supporting the land market [1,2]. Identifying parcel boundaries and areas for revenue has been a long-standing practice that dates back millennia. It laid the foundation for the modern era of land administration that supports more functions: land use, land value, land development, and land tenure [2,3].

Despite the long-standing tenure security function of land administration practices, studies estimate a significant proportion of the world's land rights are undocumented, owing partly to the slow, expensive, and expertise-dependent cadastral surveying and land registration conventional approach [4,5]. Additionally, high rates of urbanization have been challenging land tenure recordation for the past few decades [6–8].

In response, the United Nations Committee of Experts on Global Geospatial Information Management [9] developed the Framework for Effective Land Administration (FELA) to support the achievement of Sustainable Development Goals (SDGs) in the land sector [5]. It enables benchmarking to track member states' progress on land rights security [10]. This is part of the broader push to achieve the SDGs that seek to improve people's lives while safeguarding the environment [11]. The SDGs aim at solutions to the broader global challenges caused by a lack of good land governance and efficient land administration systems [12]. Land governance is the spatial dimension of governance that refers to the sustainable and transparent management of land, property, and natural resources [2,13].

FELA highlights that conventional approaches to land administration can be slow and cost-inefficient in dealing with the rapid urbanization challenges [14]. Enemark et al. [12] also argue that it would take decades to achieve the SDGs and ensure global tenure security through the conventional land administration approach. Thus, different countries are executing Fit-For-Purpose Land Administration (FFPLA), with a primary focus on delivering tenure security in an expedited fashion [15].

Although the FFPLA approach and its executions are country-context dependent, these specific applications could provide practical experience for addressing land administration challenges of other developing nations. They can also help extend conceptual improvements concerning the spatial, legal, and institutional framework of FFPLA, and its broader applicability for effective land administration. Most recent work has been completed in this regard, in terms of assessing and documenting FFPLA cases. However, most of this work was completed before the outbreak of COVID-19 pandemic and pre-FELA eras, and more cases have emerged in the intervening years. Although COVID-19 has influences on land administration issues, studies discourse the FFPLA approach could help improve resilience to climate and pandemic-related impacts, necessitating responsive actions to maintain the SDGs [16,17].

Therefore, the purpose of this study is to identify successful global FFPLA practices and theories implemented in 2021 and 2022 that can be synthesized and extended for applicability in other land administration settings, such as rapidly urbanizing areas of the developing nations. The best FFPLA implementation practices in the study refer to the successful take-up of FFPLA executions that inform approaches for future FFPLA projects. Accordingly, the review will explore (i) how countries have contextualized and mainstreamed FFPLA implementation; (ii) how countries have addressed FELA through FFPLA during project implementation; (iii) to what extent can FELA and FFPLA be jointly pursued during project implementation, and (iv) how emerging innovations enhance FELA and FFPLA executions.

In the remaining sections, a comprehensive view of FELA and FFPLA is presented first as a background for the study. Then, the methodological approach for the study is briefly discussed. Next, a review of the contemporary innovative and conceptual FFPLA implementation practices is offered, followed by a detailed discussion and synthesis of the results. Finally, the study conclusion and recommendations are presented.

2. Background

2.1. Framework for Effective Land Administration (FELA)

The Framework for Effective Land Administration (FELA) is a high level, strategic framework that serves as a reference for UN member state countries while building, improving, monitoring, and evaluating their land administration solutions [5,9]. Forty-four countries across the globe (ten from Asia, ten from the Americas, eight from Africa, fifteen from Europe, and one from Arab states) have actively contributed to the development of FELA, and currently it is translated into different languages for ease of use [18]. FELA aims to combat worldwide tenure insecurity through rapid and sustainable land administration actions that consider all people. It is designed based on the overarching and strategic Integrated Geospatial Information Framework (IGIF) [9]. FELA has nine interrelated and necessarily overlapping pathways to guide its execution and achieve the land related SDGs. These are Governance, Institutions and Accountability, Legal and Policy, Financial, Data, Innovation, Standards, Partnerships, Capacity and Education, and Advocacy and Awareness [5,9].

The pathways serve as a guide for meeting the requirements and achieving the overall FELA goals. Table 1 shows the requirements to achieve the goals through the pathways. FELA makes direct reference to the underlying pragmatic philosophy, elements, and guidance of FFPLA.

Table 1. FELA: Goals, Requirements, and Pathways [9]. From Framework for Effective Land Administration, by UNGGIM. ©United Nations 2022. Reprinted with the permission of the United Nations.

FELA Goals	FELA Requirement	FELA Pathway
Transparency and accountability increased	Accountable and transparent Governance	Governance, Institutions and Accountability
Gender-responsive and inclusive of vulnerable groups	Inclusive and recognize all forms of Tenure	Policy and Legal
Affordable investments and economic returns assured	Affordable with sustainable business models	Financial
Reliable data and service quality attained	Data maintained, secure and not duplicated	Data
Responsible and innovation oriented	Upgradable systems and approaches	Innovation
Interoperability and integration supported	Considers internationally agreed Standards	Standards
Cooperation, partnerships, and participation leveraged	Strengthens partnerships and supports collaboration	Partnerships
Capacity, capability, knowledge transfer and exchange attained	Facilitates capacity development and knowledge transfer	Capacity and Education
National engagement and communication enhanced	Advocates for land administration and management	Advocacy and Awareness

2.2. The Fit-For-Purpose Land Administration (FFPLA) Concept

Preceding FELA, the FFPLA approach, with similarities to the "Minimum Viable Product" (MVP) philosophy, proposes to create an entry point for addressing the basic societal needs of tenure security that would upgrade with quality and scope over time [12,13]. The fit-for-purpose concept is best explained in Enemark et al. [14] as *"as little as possible–as much as necessary"*. The approach can be tailored to a country's specific tenure security strategies and does not depend on cutting-edge technology and lengthy field surveys.

The FFPLA approach is seen as a top-down execution that entails forging alliances, launching projects, and enhancing capability within the ranks of the executive branch [13,19]. The strategy and methods of implementation will also differ depending on the nation, the kind of tenure, the type of land use, the topography, and the density of parcels [14]. It is a participatory approach for recording parcel information with inexpensive technologies, striving for complete coverage first [5,20]. For instance, as an alternative to conventional aerial photography, UAVs could be applied for updating the rapidly changing (peri-) urban areas' land administration. High-resolution satellite imagery is an alternative data source for cadastral base mapping and updating. GNSS-enabled smartphones enhanced the notion of crowdsourcing for mapping and updating own land rights. Automatic parcel boundary extraction from images becomes promising with artificial intelligence and machine learning developments [5,20,21]. Compared to the conventional field surveying and aerial photography procedures, these technologies are: flexible in terms of use, inexpensive to purchase, work in all terrain types and environments, encourage local participation and engagement, and deliver reliable information to meet the current demand and upgrade to satisfy future needs [22].

The FFPLA concept gained traction as an alternative to the conventional approach after the first joint publication by the FIG and the World Bank in 2014 [15]. The development of the ISO 19,152 Land Administration Domain Model (LADM) in 2012, accompanied by the Social Tenure Domain Model (STDM), also contributed to its quick acceptance [20].

FFPLA has seven characteristic elements (Table 2) and three fundamental frameworks (spatial, legal, and institutional) (Figure 1). The purpose of FFPLA is to ensure tenure security that meets the desirable qualities (the characteristic elements) of the approach through a simplified spatial, legal, and institutional framework—the building blocks [23].

Table 2. Elements of the FFPLA approach [15].

FFP Element	Purpose
Flexible	in the spatial data capture approaches to provide for varying use and occupation.
Inclusive	in scope to cover all tenure and all land
Participatory	in approach to data capture and use to ensure community support.
Affordable	for the government to establish and operate, and for society to use.
Reliability	in terms of information that is authoritative and up-to-date
Attainable	to establish the system within a short timeframe and within available resources.
Upgradeable	with regard to incremental improvement over time in response to social and legal needs and emerging economic opportunities.

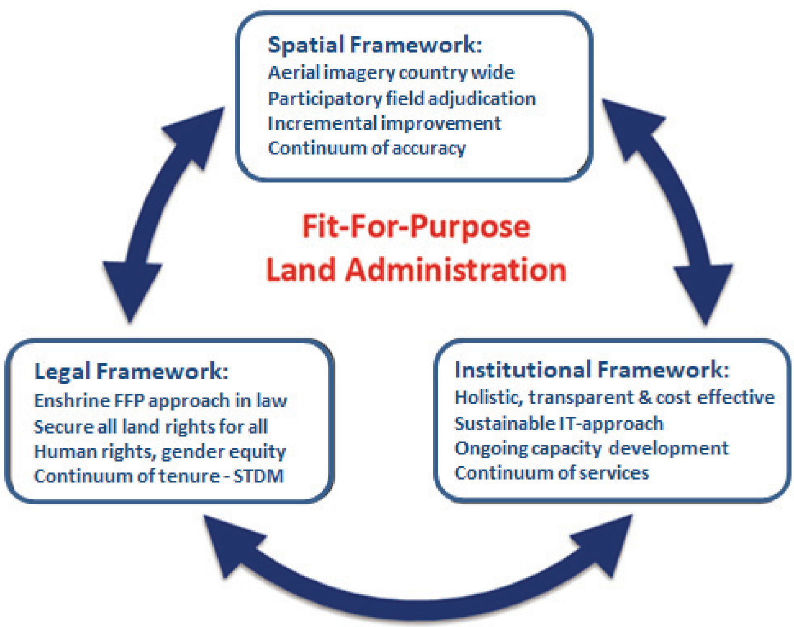

Figure 1. FFPLA fundamental frameworks [14].

According to Enemark et al. [12,14], the spatial framework establishes a cost-effective and feasible method of dividing land into spatial units and is a foundation for registering land rights. The legal framework provides fit-for-purpose innovative and flexible land right registration techniques that need legal endorsement. The institutional framework proposes policy frameworks for an efficient and accountable institutional setup to deliver transparent and accessible land information for all.

2.3. FFPLA and FELA Alignment

The FELA pathways align with the FFPLA approach. For example, FELA's transparency and accountability are the foundations of the FFPLA institutional framework. Moreover, the continuum of tenure [12] ensures land and property rights for all, inclusive of gender and vulnerable groups. Affordable investments and economic returns can be ensured by flexible ICT solutions and open-source technologies, in addition to implementing a sustainable business model. Reliable data can be generated from satellite/aerial image visible boundaries, focusing on the purpose rather than technical standards. Innovative updating and upgrading approaches are encouraged for ongoing improvements responsive to societal needs and economic growth. The ISO-endorsed LADM and the derived STDM confirm an adaptable interoperability layer with other stakeholders. Institutional collaboration and partnership are targeted toward supporting the recording and maintenance of land rights evidence, leveraging the private sector's capacity, knowledge, and finance in the land sector. Capacity development and knowledge transfer bring new skills to the public and private sectors to enhance implementation. Advocacy and awareness are included to establish national engagement and commitment at the societal, organizational, and individual levels. Although FFPLA was conceived before FELA, there is a strong alignment between them. Table 3 depicts the FFPLA alignment with the FELA pathway goals, adapted from [9,14].

Table 3. FFPLA alignment with the FELA pathway goals adapted from [9,14].

FELA Pathway	FELA Goal	FFPLA Alignment
Governance, Institutions, and Accountability	Transparency and accountability increased	Good land governance rather than bureaucratic barriers Integrated institutional framework rather than sectorial silos Transparent land information with easy and affordable access for all
Policy and Legal	Gender-responsive and inclusive of vulnerable groups	Ensuring gender equity for land and property rights A continuum of tenure rights rather than just individual ownership
Financial	Affordable investments and economic returns assured	Flexible ICT approach rather than high-end technology solutions Aerial/satellite imagery rather than field surveys Sustainable business model that secures land administration institutions' financial constraints
Data	Reliable data and service quality attained	Visible boundaries rather than fixed boundaries Accuracy relates to the purpose rather than technical standards Spatial framework that provides reliable and up to date data
Innovation	Responsible and innovation oriented	Adopts procedures for updating/upgrading and ongoing improvement of the spatial framework
Standards	Interoperability and integration supported	Adopts LADMSTDM Other international ICT interoperable standards.
Partnerships	Cooperation, partnerships, and participation leveraged	Supports Public Private Partnerships and collaboration to be leveraged in the land sector
Capacity and Education	Capacity, capability, and knowledge transfer attained	Facilitates capacity development and knowledge transfer through adequate measures of education and training
Advocacy and Awareness	National engagement and communication enhanced for effective land administration	Promotes advocacy, awareness creation, and knowledge sharing and dissemination for effective land administration

3. Materials and Methods

The execution of the FFPLA and implementation of FELA approach varies from country to country based on the prevailing and available spatial, legal, and institutional frameworks. However, it is conceivable to identify successful implementations and developments and create generalization to extrapolate from and apply to other land administration settings.

The constructivist/interpretivist research paradigm is identified as a framework for the study. It seeks a deeper understanding of a concept and tends to develop subjective meanings for experiences [24]. The paradigm is helpful in discerning background knowledge to subsequently improve practices, besides encompassing numerous methodologies to achieve the research objectives [25]. Following from this, a systematic review is adopted as the overarching research methodology, an approach for identifying, analyzing, and integrating relevant study outputs on a subject topic to address a specific research question or hypothesis [26,27]. Different authors such as [20,28–30] use this approach in the land administration domain studies.

The study is purposely confined to recent studies and focuses on contemporary FELA and FFPLA developments following emerging geospatial technologies. Furthermore, earlier FFPLA practices, such as those in Ethiopia and Rwanda, are well explored, and insights that contributed to today's innovative approaches are extracted [15,31–33]. That said, as for the first task of the systematic research approach, i.e., searching and identifying relevant literature, the study employs already acknowledged literature by Enemark et al. [10], for both FFPLA conceptual innovations (Volume I) and practical implementations (Volume II) across the globe. All the articles were published in 2021 in the Land Journal, an international scholarly and open-access journal that focuses on land use and land management issues.

However, the search for articles is extended to other renowned and reputable land administration journals: Land Use Policy (LUP), Survey Review (SR), and International Journal of Geo-Information (IJGI). The Land journal is also double-checked to maximize the possibility of receiving relevant papers that might not be included in the two volumes of publications. Further searches are conducted in the OICRF (https://www.oicrf.org/, accessed on 5 July 2022) archive of the International Federation of Surveyors (FIG). Figure 2 is the flow diagram for the identification of studies from the reputable journals and the OICRF databases (adapted from PRISMA[1]).

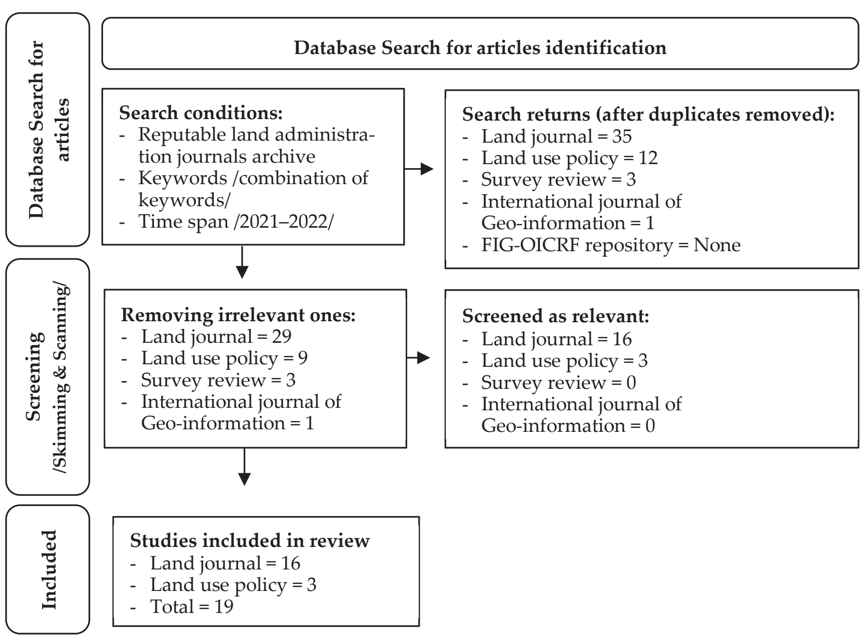

Figure 2. Literature identification flow-diagram.

Multiple searches were run in the first week of July 2022 for the Science Direct, Taylor & Francis, MDPI, and OICRF repositories with the same periods (2021 to 2022) and keyword combinations ('conceptual', 'innovative', 'Fit for purpose', 'land administration', 'cadaster', 'country implementations', 'executions', 'tenure security', 'geospatial tools', 'public-private partnership', 'maintenance', 'update/upgrade', 'feature', 'boundary', 'extraction', 'delineation'). The keywords (combined by 'AND'/'OR') are expected to provide studies relevant to the Enemark et al. [10] collections on the FFPLA conceptual and technical innovations.

The search yielded thirty-five (35) articles from Land (including the items in the two volumes), twelve (12) papers from LUP, three (3) from SR, and one (1) from IJGI. The search for the FIG-OICRF repository delivered no results. Non-relevant publications are weeded out by swiftly skimming and scanning (probing a bit deeper) the title and abstract of each article, a time-honored approach to quickly reviewing and getting the substance of a document [34]. Thus, a total of 19 articles from the Land (16) and LUP (3) journals are identified, which focus on FFLA practical country implementations (13) and conceptual innovations (6), and thoroughly examined (Figure 2).

The overall methodological approach to identify the best FFPLA implementation practice is depicted in Figure 3.

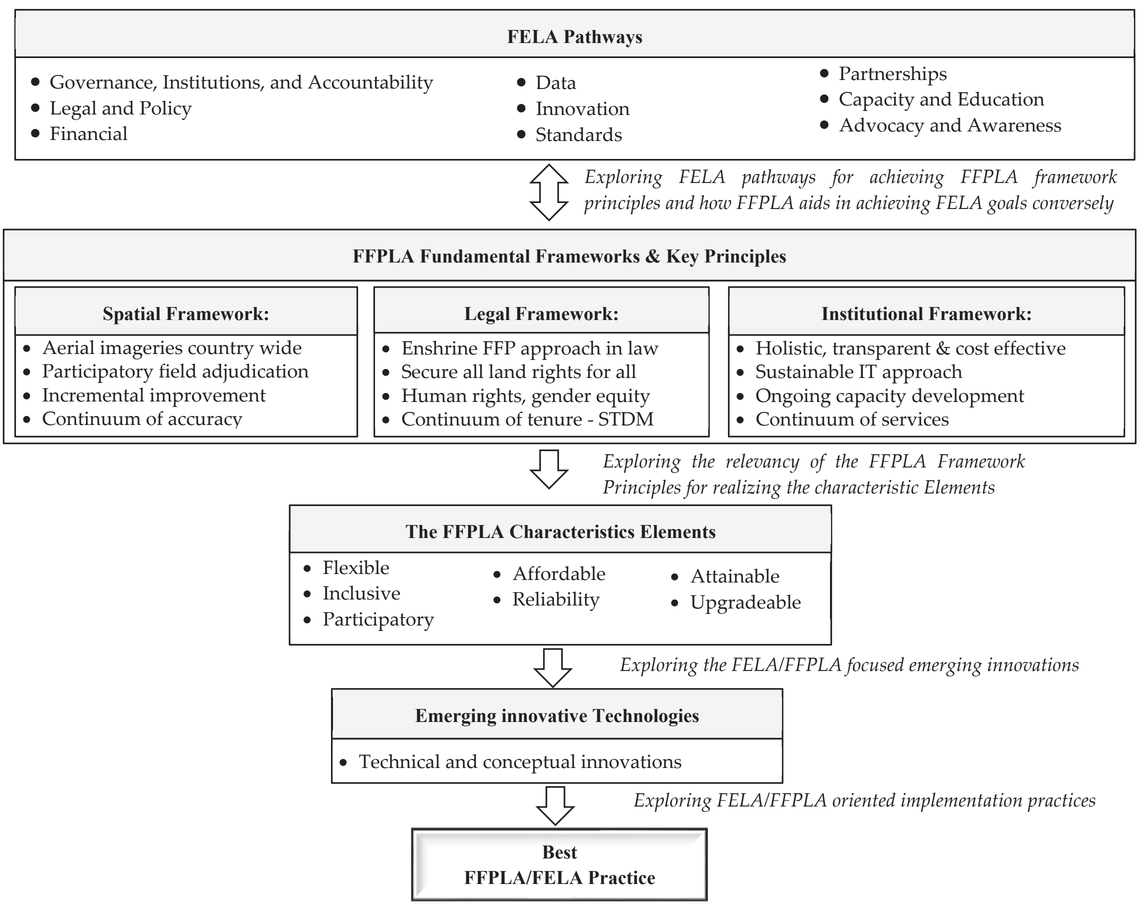

Figure 3. The research methodology.

Based on the review, the countries' responses to the FFPLA core principles and FELA pathway goals are collected using a checklist for ease of further comparison to characterize successful executions, as done in multiple works [35–40]. For instance, van der Molen et al. [40] compared nine African countries to identify how land policy documents are composed. Kitsakis et al. [35] comparatively analyzed and depicted the legal concepts for 3D real property in selected case study countries. Augustinus [36] compared and identified land administration best practices in five countries.

FELA is utilized to examine and describe land administration situations. For instance, Bennett et al. [20] applied the nine paths to discover and link land administration maintenance concerns with available solutions. García-Morán et al. [41] employed the FELA pathways to determine the roles and responsibilities of the involved actors in securing land rights while developing an innovative public-private partnership. Thus, the FELA nine pathways are utilized to explore global implementation of the FFPLA fundamental framework key principles. Best practices are anticipated to achieve the FFPLA desirable qualities and meet the FELA goals. Furthermore, conceptual innovations in spatial, legal, and institutional frameworks are being investigated to extend enhanced FFPLA implementation practices to a broader range of land administration settings (Figure 3).

4. Results

Although the primary concern of FFPLA is resolving the global land tenure security issues, currently, it is expanding to address the other fundamental functions of land administration (land value, land use, and land development) [13]. The approach strives to achieve a flexible, inclusive, participatory, affordable, reliable, attainable, and upgradeable land administration system through the key principles of the fundamental framework. Several studies agree with the benefits of the FFPLA for ensuring tenure security in a short period and at a reasonable cost [10,42].

The UN-endorsed FELA guides member countries in building, improving, or monitoring their land administration systems. It could be aligned with the FFPLA approach and enhance its implementation, thereby achieving the FELA pathway goals. Furthermore, emerging innovations and ICT solutions promote the FFPLA approach by providing inexpensive, reliable, and faster tools for tenure mapping and security services [13,43]. Best FFPLA implementation practices are anticipated to integrate and realize FELA pathways and FFPLA framework principles, supported by FELA/FFPLA-focused contemporary innovations and conceptual developments.

The review results are presented according to the study flow depicted in the research methodology (Figure 3). First it describes the status of FFPLA on a global scale through the summary of the widespread contemporary FFPLA implementation practices. The result further demonstrates how the FELA pathway goals enhance the execution of the FFPLA fundamental framework principles and, conversely, how FFPLA aids in achieving FELA goals. Successful application of the FFPLA principles realizes its characteristic elements in land administration practice. FELA/FFPLA focused innovative concepts and technologies are also helping secure land ownership rights in a fit-for-purpose manner. FELA and FFPLA collaborate to provide the best implementation practices, which are discerned based on the countries' achievements in meeting the FELA pathway goals and the FFPLA fundamental framework principles.

4.1. Mainstreaming of FFPLA Implementation Practices

Global donors and development partners, such as the World Bank, are now requesting that the FFP approach be used in project designs to support land administration projects [9,44]. However, even before the FFPLA approach got global attention (pre-2010), some African and Asian countries used a cost-and time-effective method to improve their land administration and management systems. Byamugisha [45] reviewed land administration executions in China and Vietnam and compared them with two remarkable practices carried out by Ethiopia and Rwanda.

The central government of China scaled up a land registration project initiation started by one province in 2005 that covered the registration and certification of about 98.87 million hectares of rural land across the country. The approach was participatory and employed high-resolution satellite imagery and ground surveys for highly-valued contractual land use rights. Vietnam started a participatory land right registration and land use right certification in 1994 that involved all levels of the government down to the local community representatives. After six years, it was possible to issue land use rights certificates for about 90 percent of the rural land and 16 percent of the urban areas. In five years, Rwanda demarcated, adjudicated, and registered all the nation's rural and urban land parcels at an estimated cost of USD 8 per parcel. Ethiopia also issued the second-level certification for about 20 million rural landholdings within six-years at an average cost of USD 8.5 per parcel.

These Asian and African countries land registration and certification success stories are due to their pragmatic strategy and participatory approach encompassing all levels of government, from provincial to district to commune [45]. After the FFPLA concept has gained global acceptance, its implementation is increasing across a broader range of land management functions [13], pending accuracy, and high-tech demands for over-time improvement.

4.1.1. FFPLA, Improving the Existing Tenure Security Practices

Mozambique has implemented the FFPLA after facing several data quality issues in addition to the time and budget-intensive nature of the conventional method [46]. The registration approach involved connecting people, processes, and technology for accurate and complete data collection while saving cost and time. Community participation, inexpensive technologies, and user-friendly applications are common to most FFPLA implementation practices, such as in Uganda, Kenya, Zambia [47], Nepal [48], Colombia [49,50], and Benin [51].

Another study by Chigbu et al. [52] examined successful FFPLA implementation in Ghana, Kenya, and Namibia. It was executed to secure land rights in different land administration settings: peri-urban (Kenya), urban (Namibia), and rural (Ghana). The study evaluated these implementations in light of the fundamental principles of FFPLA. Namibia adopted the FFPLA principles but with a fixed boundary approach. However, according to Martono et al. [53], the "fixed-boundary" approach is time and resource consuming for it needs establishing monuments and determining the coordinates with accurate positioning techniques. Ghana and Kenya also exercised many of the framework principles well, with considerable attention to administrative flexibility, gender equity, good governance, and institutional integration.

Martono et al. [53] proposed a fit-for-purpose approach to Indonesia's ambitious plan for systematic registration of 135 million parcels, which is falling behind schedule owing to spatial and legal constraints. According to the study, the legal requirement for a high-precision "fixed-boundary" survey over erected boundary monuments caused poor development. The cost of preparing the monuments has also made registration too expensive. Although the "fixed-boundary" approach is implemented in Benin [51] and Namibia [50], Martono et al. [53] recommended the "general-boundary" for cost and time effective parcel boundary delineation, setting aside the fixed boundary approach for future enhancement and upgrading, as proposed in the FFPLA approach.

Becerra et al. [49] have looked into a participatory fit-for-purpose approach executed in Colombia to deliver a reliable basis for boundary dispute resolution. The communities, after hands-on training, mapped parcel boundaries under expert supervision using advanced yet user-friendly geospatial tools: a hybrid of an open-source PostgreSQL database system and a proprietary ESRI's Collector app for mobile data collection connected with a GNSS receiver. A similar boundary data collection setting was done in Colombia [50] and Benin [51]. According to the study, conflicting data from various government sectors due to a lack of institutional integration is the reason for border disputes.

4.1.2. Assessing Suitability of the FFPLA Spatial, Legal, and Institutional Frameworks

Musinguzi et al. [42] investigated three FFPLA pilot programs in different parts of Uganda and highlighted spatial, legal, and institutional framework gaps for transforming the present Western-style land management system into an efficient FFPLA. The study identified promising practices from the pilot implementations. Less-educated land administration assistants and paralegals (instead of lawyers and courts) were employed to produce parcel boundary maps, resolve minor disputes, and carry out the registration. Practical implementation practice is conducted in Nepal [48] for a similar purpose, assessing the viability of the FFPLA approach. Studies in Caribbean SIDS [54], Ecuador [55], and South Africa [56] also analyzed the available spatial, legal, and institutional frameworks.

Panday et al. [48] explored two pilot projects in rural and peri-urban settings executed to assess the viability of the FFPLA approach for identification, verification, and recordation (IVR) of informal land rights in the Nepalese context. The study proved the potential of emerging geospatial technologies (high-resolution satellite images and freely available open-source software like STDM) for collecting, verifying, and recording spatial and legal data in a time and cost-efficient manner. The study by Antonio et al. [47] also demonstrated the STDM to ensure cost and time-effective tenure security under the FFPLA framework principles. Moreover, the approach employed locally trained “grassroots surveyors” and highly involved the communities to reduce disputes while delineating parcel boundaries, as has been done in Uganda, Kenya, and Zambia [47]. The authors also suggested that implementing the study recommendation could minimize the predicted time (by 4–5 years) and cost to legitimize the reported 10 million informal land holdings.

Griffith-Charles [54] assessed whether the Caribbean Small Island Developing States (SIDS) land administration experience is fit-for-purpose oriented or favorable to adopting the FFPLA approach in future development. The author noted that some of the islands’ land administration policies are aimed at securing tenure (Trinidad and Tobago), boosting the economy (Barbados and Saint Lucia), or protecting the environment (Jamaica) regardless of the FFPLA approach. As in the study by Todorovski et al. [55] and Williams-Wynn [56], Griffith-Charles [54], also highlighted the existence of legal, spatial, and institutional frameworks that favor the FFPLA approach. The spatial framework, for instance, proposes readily available geospatial tools and active community participation for spatial data collection.

From the FFPLA perspective, Todorovski et al. [55] analyzed the Ecuadorian land administration’s aspiring plan to establish a cadaster across the continent. According to the study, the existing spatial, legal, and institutional framework is aligned with the FFPLA framework principles moderately to poorly. The study advised that the medium and low-scoring spatial, legal, and institutional frameworks be addressed appropriately to achieve the ambitious plan in a fit-for-purpose manner. Musinguzi et al. [42] also conducted a similar study in Uganda to identify the spatial, legal, and institutional framework gaps to transform the existing system to the FFPLA approach.

Similar with a study conducted in Caribbean and Ecuador, Williams-Wynn [56] explored the feasibility of the existing land administration system of South Africa to adapt the FFPLA approach and provide a reliable tenure security to all citizens. The study identified positive aspects for implementing the FFPLA approach in South Africa, with few but relevant improvements to the existing spatial, legal, and institutional frameworks. The author further proposed the FFPLA approach to legitimate undocumented rights and updates the existing parcel boundaries using innovative geospatial technologies.

4.1.3. LADM and STDM, Enhancing FFPLA Implementation

LADM as a standard data model simplifies data exchange within and among land administration systems and supports application software development [57]. Benin created a low-cost commercial Android socio-app for the administrative data collection, based on its LADM profile [51]. Morales et al. [50] collected cadastral data in Colombia that fully complies with the LADM standard and the country profile. STDM is an open-source software tool developed based on LADM to support countries with weaker tenure security coverage [58].

Antonio et al. [47] have investigated three FFPLA practices performed in Uganda, Kenya, and Zambia using the STDM tool. The study proved that STDM is quite effective in developing the FFPLA spatial framework and improving tenure security at an affordable cost. More than 181,000 informal settlements were enumerated and mapped using the STDM tool in Uganda's 14 secondary cities. Kenya and Zambia issued certificates of customary land occupancy to 944 and 1794 households, respectively, including women beneficiaries. Similarly, after conducting a pilot test, Panday et al. [48] showed the potential of the STDM to quickly legalize sizable informal land holdings.

Mekking et al. [51] conducted a pilot FFPLA strategy based on the LADM, tending to improve and speed up the existing cost-and time-intensive conventional approach in Benin. Because the parcel boundaries were not visible on the satellite image, the landowners were strongly encouraged to actively participate in identifying and physically labeling their parcel boundaries and associated dispute settlements. Then the boundary coordinates are collected and verified using low-cost GNSS receivers and commercial geo-data collection software. According to the authors, the pilot FFPLA implementation could improve the current practice to a more cost-and time-effective approach for national tenure security coverage. Colombia adopted a matching methodology for a reliable parcel boundary data collection utilizing GNSS-enabled mobile receivers and user-friendly geospatial tools [49,50].

Morales et al. [50] also applied LADM for a participatory cadastral data collection procedure in Colombia. It employed a cell phone connected with RTX (Real Time Extended) enabled external GPS receivers and an STDM-based field survey module contingent on ESRI's ArcGIS collector app with cloud storage. The landowner walks along his parcel, collecting as many points as necessary to form the parcel boundary polygon on top of the background orthophoto or satellite image. Later, the collected data is analyzed for topological correctness. The overall procedure is tested through several case studies in Colombia with different land rights forms. According to the authors, it is capable of addressing the requirements of the land administration actors (surveyors, landowners, and land administrators) for fast and reliable service delivery. To this end, they recommended evolving through the fit-for-purpose major steps: socialization, planning, training, data collection, post-processing, public inspection, and recordation.

The review touches on a few of the numerous available cases, various sizes, and scope of applications of the FFPLA approach. Certain African and Asian countries explored a fit-for-purpose strategy to provide land administration services before FFPLA gained international notice. After gaining global traction, the FFPLA approach is being used in various countries to improve existing tenure security practices. Nations further conducted pilot projects to evaluate the viability of the legal, spatial, and legal frameworks and identified a gap to fill for FFPLA execution. LADM and STDM are also contributing to successful FFPLA implementation practices. Table 4 provides the summary of the reviewed FFPLA implementation practices and studies.

Table 4. Summary of FFPLA implementation practices and studies.

Purpose of Implementation	FFPLA Application Context	Country	Author(s)
Improving the existing tenure security practices	Connecting people, processes, and technology to improve the existing land administration practice	Mozambique	Balas et al. [46].
	Using FFPLA as a guideline to improve tenure security in peri-urban, urban, and rural land administration settings	Kenya, Ghana, Namibia	Chigbu et al. [52]
	Applying the FFPLA "general-boundary" approach to enhance systematic registration	Indonesia	Martono et al. [53]
	Enhancing boundary dispute resolutions by the FFPLA approach	Colombia	Becerra et al. [49]
Assessing suitability of the spatial, legal, and institutional frameworks	Identifying spatial, legal, and institutional framework gaps for FFPLA implementation	Uganda	Musinguzi et al. [42]
	Evaluating the FFPLA approach for identification, verification, and recordation (IVR) of informal land rights	Nepal	Panday et al. [48]
	Assessing the current land administration experience for adopting the FFPLA approach in future development.	Caribbean	Griffith-Charles [54]
	Assessing the alignment of the FFPLA framework principles with the existing spatial, legal, and institutional frameworks	Ecuador	Todorovski et al. [55]
	Investigating the feasibility of the existing LA system to adapt FFPLA	South Africa	Williams-Wynn [56]
LADM and STDM, enhancing FFPLA implementation	Employing the STDM to enhance the FFPLA approach	Uganda, Kenya, and Zambia	Antonio et al. [47]
	Applying LADM to improve and speed up the conventional land administration approach	Benin	Mekking et al. [51]
	Applying LADM for a participatory cadastral data collection	Colombia	Morales et al. [50]

4.2. Addressing of FELA Pathways through FFPLA Implementations

FELA considers emerging global policies and guidelines to ensure the achievement of the continuum of land rights, which FFPLA strives to attain through the fundamental framework principles and implementation strategies [14,41]. Achieving the FFPLA key principles would lead to the realization of the FELA pathway goals and vice versa.

The FELA transparency and accountability pathway is achieved by implementing the FFPLA good land governance, transparent land information, and integrated institutional framework. The goals for being gender-responsive and inclusive of vulnerable groups are realized through the key principles of gender equity for land and property rights. Countries' flexible ICT and aerial/satellite image implementation could make the system affordable for the government to set up and operate.

Reliable data and service quality are attained through the active participation of the community while identifying and delineating their parcel boundaries over aerial or satellite imagery. Emerging technologies and techniques provide the opportunity to map the rights, restrictions, and responsibilities in different ways, helping achieve the FELA goal of a responsible and innovative system update and upgrade. FFPLA executions adapted the ISO-endorsed LADM and guided partnerships through explicit roles and duties, promoting the attainment of the FELA interoperability and integration standard and partnership goals.

The countries' background in conventional educational programs, on-the-job training, peer-to-peer learning, and experience sharing, professional dialogue, and seminars would contribute to the FELA. It is necessary to plan and execute advocacy and awareness programs to favor the active participation of the stakeholders and the general public in the land administration tasks and decision-making on land problems.

The countries have mainstreamed different approaches with their legal, spatial, and institutional frameworks while implementing FFPLA. Consequently, the FFPLA-oriented practices helped achieve the FELA pathway goals. Table 5 summarizes the mutual and generalized FFPLA implementation practices expected to address the FELA pathway goals [5].

Table 5. Anticipated FFPLA implementation practices to address the FELA pathway goals.

FELA Pathway	FELA Requirement	Countries' FFPLA Practice /Based on the Review/	Case Example Country
Governance, Institutions and Accountability	Accountable and transparent governance	- Institutional integration with clear responsibilities - Transparent and participatory conflict resolution - Transparent and accessible land administration - Integrated and harmonized stakeholders participation - Flexible and good governance workflows - Unified registration system for data integrity, quality, and sharing	Benin, Colombia, Mozambique, Namibia, Nepal, Ghana, Kenya, Uganda
Policy and Legal	Inclusive and recognize all forms of tenure	- Legal recognitions of available forms of tenure system - Legally recognize social equity to land and property rights - Public awareness for conscious participation in property and land right registration	Benin, Colombia, Mozambique, Namibia, Nepal, Ghana, Kenya, Uganda
Financial	Affordable with sustainable business models	- Participatory data collection with affordable technologies - Simple field surveys for non-visible boundaries - Set of guidelines and standards for inexpensive right registration - Parcel value-based charge for expense revenue.	Benin, Colombia, Mozambique, Namibia, Nepal, Ghana, Kenya, Uganda
Data	Data maintained, secure and not duplicated	- A hybrid of modern and traditional technologies and techniques for spatial data collection - Clear and participatory procedure for reliable spatial framework - Accuracy corresponds to the purpose or reality - Legal recognition for fit-for-purpose parcel data - Ground survey technique for small areas	Benin, Colombia, Mozambique, Namibia, Nepal, Ghana, Kenya, Uganda
Innovation	Upgradable systems and approaches	- Innovative tools and techniques for flexible and participatory parcel data collection and storing - Organizational process and incentives for innovative data model and mapping standards	Benin, Colombia, Mozambique, Nepal, Uganda
Standards	Considers internationally agreed standards	- Adopt LADM - Employ STDM - Developed desired standards for archives, and digital records	Mozambique, Benin, Nepal, Kenya, Ghana, Namibia, Uganda, Colombia
Partnerships	Strengthens partnerships and supports collaboration	- Fortify partnership support and collaboration in organizing and providing awareness and capacity building activities - Encourage partners' technical and financial support to capacitating local governments land institutions	Benin, Colombia, Nepal, Uganda
Capacity and Education	Facilitates capacity development and knowledge transfer	- Capacity building training for grassroots surveyors, local land administration assistants, community members - Skill gap-based training packages and capacity building program	Colombia, Mozambique, Nepal, Uganda,
Advocacy and Awareness	Advocates for land administration and management	- Role-play training to aware the community - Community awareness for providing reliable and quality datasets - Political awareness and government engagement for securing land rights at scale.	Colombia, Mozambique, Nepal, Uganda,

4.3. Connecting FFPLA Elements, Principles and Frameworks, for Real Results

As seen, the articles reviewed above cover the FFPLA experiences in 15 countries across the globe (Benin, Caribbean Islands[2], China, Colombia, Ecuador, Ghana, Indonesia, Kenya, Mozambique, Namibia, Nepal, South Africa, Uganda, Vietnam, and Zambia). The study by Byamugisha [45] is to draw lessons from China and Vietnam pre-FFPLA implementation and identify future upgrading challenges. Some studies explored the holistic application of FFPLA for improving the existing tenure security practices [46,49–52]. The study cases in Uganda, Nepal, South Africa, Ecuador, and the Caribbean Islands assessed the favorable legal, spatial, and institutional conditions for possible FFPLA implementations. LADM and STDM were also investigated and proved important for cost and time effective FFPLA execution [47,50,51]. The study by Becerra et al. [45] aspired to provide a reliable FFPLA basis for boundary dispute resolution.

According to the purpose and motivation of this study, i.e., to identify the contemporary status and best implementation practices of FFPLA for tenure security, the holistic executions in Benin, Colombia, Ghana, Kenya, Mozambique, Namibia, Nepal, and Uganda are further analyzed based on the FFPLA fundamental framework key principles.

While successfully implementing the key principles under each fundamental framework, the FFPLA-practicing countries would address one or more of the FFPLA characteristics elements. Table 6 summarizes the global implementations of FFPLA key principles and the anticipated elements to be achieved.

Table 6. Global implementations of FFPLA key principles and the expected elements to achieve.

FFPLA Core Framework	FFPLA Key Principle	FFPLA Element to Achieve	Case Example Country
Spatial	Visible (physical) boundaries rather than fixed boundaries	Flexible: in the spatial data capture approaches (general boundaries, simple field surveys, fixed boundaries) Affordable: visible boundary approach and simple survey techniques are less time and capacity demanding.	Colombia, Mozambique, Nepal, Ghana, Kenya, Uganda
	Aerial/satellite imagery rather than field surveys	Affordable: for it is cheaper than field surveys and much less time and capacity demanding. Participatory: in approach to data capture and use to ensure community support. Reliable: in terms of information that is authoritative and up-to-date for disputes are solved in the field at the presence of the claimants	Colombia, Mozambique, Namibia, Nepal, Ghana, Kenya, Uganda
	Accuracy relates to the purpose rather than technical standards	Flexible: in the spatial data capture approach (mapping scale and technology) to provide for varying use and occupation. Affordable: for it does not employ highly accurate and precise technical standards and technologies to achieve these	Benin, Colombia, Mozambique, Namibia, Nepal, Ghana, Kenya, Uganda
	Demands for updating and opportunities for upgrading and ongoing improvement	Upgradeable: with regard to incremental improvement over time in response to social and legal needs and emerging economic opportunities	Benin, Colombia, Mozambique, Namibia, Nepal, Ghana, Kenya, Uganda
Legal	A flexible framework designed along administrative rather than judicial lines.	Flexible: in recording and registering land rights by administrative institutions under delegated authority, rather than being dependent on judicial lines. Affordable: for securing land rights are believed to be time and resource consuming both for the courts and the land right claimant.	Benin, Mozambique, Namibia, Nepal, Ghana, Kenya, Uganda
	A continuum of tenure rather than just individual ownership	Inclusive: in scope to cover all tenure and all land Reliable: for it registers all tenure without owners' discrimination.	Benin, Colombia, Namibia, Nepal, Ghana, Kenya, Uganda
	Flexible recordation rather than only one register	Flexible: in national as well as local recordation of the various tenure types Participatory: to integrate local categorization of land rights Affordable: for the citizens particularly the poor to enable and the country to scale up the system.	Benin, Mozambique, Namibia, Nepal, Ghana, Kenya, Uganda
	Ensuring gender equity for land and property rights.	Inclusive: in securing landholding rights and tenure security to all social dimension Reliable: for it ensures tenure security irrespective of gender or social dignity.	Benin, Colombia, Mozambique, Namibia, Nepal, Ghana, Kenya, Uganda

Table 6. *Cont.*

FFPLA Core Framework	FFPLA Key Principle	FFPLA Element to Achieve	Case Example Country
Institutional	Good land governance rather than bureaucratic barriers	Reliable: in the service and the information it delivers.	Benin, Mozambique, Nepal, Uganda
	Integrated institutional framework rather than sectorial silos	Flexible: in handling local land right and tenure security issues to deliver customer oriented and accessible service Affordable: for local service access due to the institutional integration	Benin, Colombia, Mozambique, Namibia, Nepal, Ghana, Kenya, Uganda
	Flexible ICT approach rather than high-end technology solutions	Flexible: to begin with attainable ICT solutions, employing Free and Open-Source Software (FOSS), flexible to accommodate changes, Attainable: to establish the system within a short timeframe and within available resources. Upgradable: to new ICT technology and platforms over time.	Benin, Mozambique, Namibia, Nepal, Ghana, Kenya, Uganda
	Transparent land information with easy and affordable access for all	Reliable: in terms of information that is authoritative and up-to-date Affordable: for it provides easy and inexpensive access for all	Benin, Colombia, Mozambique, Namibia, Nepal, Ghana, Kenya, Uganda

4.4. Recognition That Both FELA and FFPLA Innovation Oriented

The review discerned the global effort to implement the FFPLA approach for tenure security, which satisfied the fundamental framework principles, and the FELA pathway goals. The contribution of emerging innovative tools and technologies is remarkable for documenting and securing the pile of unregistered land rights across the globe. Accordingly, significant efforts are being made to back the implementation of practices with innovative geospatial tools and developments. In this context, UN organizations such as the Food and Agriculture Organization (FAO), the Global Land Tool Network (GLTN), and the World Bank (WB) are providing outstanding support for the development and use of innovative tools and technologies for land tenure security [9].

The FFPLA fundamental framework and the FELA pathway goals favor applications of emerging innovations for fast and affordable capturing and maintenance of land information. Various issues also need to be given attention and addressed by utilizing innovative approaches and developments. For example, the conventional surveying field work for parcel boundary identification and collection is time-and resource-intensive [3,59,60]. Maintenance (update/upgrade) of land information systems is not yet regarded as critically important as developing new ones [20]. Even with a fit-for-purpose strategy, finance is one of the vital issues in establishing a land administration system that ensures tenure security [41].

Although there are good practices for cadastral data update, Biraro et al. [61] contend that much work is still required for verified updating procedures, sustained financial and technical capabilities, and identifying concerned institutions. Moreover, cadastral data update/upgrade is becoming a challenging task because of the dynamic nature of people-to-land relationships [20,61]. Bennett et al. [20] reviewed a range of literature concerning land administration maintenance before and after the commencement of FFPLA. The study found that while the previous times' primary concern was establishing the land administration system, the contemporary era concept and implementation still give less attention to system maintenance (update/upgrade). After a thorough analysis of core maintenance concerns based on the review results, the authors have developed a "Consolidated Analytical Model of Land Administration Maintenance" that illustrates possible ways to maintain the system. They have also proposed using the already available solutions and emerging innovations to core maintenance issues based on the FELA pathways. The model provides a comprehensive outlook on the existing maintenance approaches and future improvement prospects. The authors recommended using the analytical model to detect recurring maintenance issues in a national setting and select the best solution(s) from the available options.

García-Morán et al. [41] pioneered a new public-private partnership (PPP) model to harness the private firms' capability, expertise, and funding in the land sector. The authors illustrated the approach with the Côte d'Ivoire Land Partnership (CLAP). They investigated the private firms' active engagement to secure land rights equally for all, as an innovative partnership for FFPLA. Côte d'Ivoire is trying to benefit the land administration from its well-known cocoa crop market through CLAP, a contractual collaboration between the government and a syndicate of private firms. The private sectors take care of the funding for efficient service delivery that targets the land administration demands of the community. The government, on the other hand, is responsible for creating a favorable political atmosphere and operating the land administration functions that benefit the private partners. According to the authors, CLAP is the first of its kind to focus on service delivery and creative process improvement through PPP based on the FFPLA approach. It could serve as a novel reference model to establish PPP that provides more room for private sector active engagement and improved land administration service delivery. The authors demonstrated the significance of the model for developing a PPP framework using the FELA pathways for financing FFPLA. Although the model's sustainability is not yet fully assessed, the preliminary achievement lies in the political willingness and the long-term commitment of the participant actors. The authors proposed that transferring the model to a similar social, legal, and institutional context could benefit.

These days, free and open-access emerging geospatial technologies are contributing much to solving global tenure security issues. However, implementation of the technologies for FFPLA could be capacity-demanding and challenging. Tan et al. [62] developed a framework to assess the existing land administration conditions for effectively utilizing geospatial technologies according to the FFPLA principles. The framework is a matrix of the seven characteristic elements of the FFPLA approach by six core capacity dimensions (regulations, political system, operational unit, social norms, land recording techniques, and software), identified from semi-structured interviews, literature, and field observations. The framework is employed to identify the present capacity conditions of Rwanda and Kenya for adapting the UAV to the land administration systems. According to the assessment result, weak accessibility of the UAV, a need for strict regulations, and capacity development are identified for Rwanda. Kenya has better access to UAVs but less technical competence for large-scale applications, which might be enhanced through market-led policies, co-production, and outsourcing.

Due to the advancement of computing technologies, various fit-for-purpose, innovative geospatial tools are also being developed and utilized to improve tenure security in developing nations. Compared to the conventional approaches, they are supposed to be faster, cheaper, more flexible, and more responsible for land rights security. Koeva et al. [21] evaluated three geospatial tools (SmartSkeMa, UAVs workflows, and Boundary delineator) and a cloud platform (PaS) against the fit-for-purpose land administration core elements. The tools were developed by the European Commission Horizon 2020 project, "its4land", to assist sub-Saharan countries' land rights registration with innovative mapping solutions [63].

Smart SketchMaps (SmartSkeMa) is a combined tool that aligns sketched information with base map data and the existing ortho-images. It is developed to enhance land tenure documentation based on local rules. The UAVs' workflows are designed to facilitate all the necessary steps for having a high-resolution ortho-image from it. It is a complete set of operational procedures, including flight planning and preparation, data acquisition, processing, and quality assessment. The boundary delineator is an open -source tool that automatically extracts visible parcel boundaries from high-resolution images by UAV, aerial, or satellite platforms and provides possibilities for the users for fast editing and accepting them for further legal approvals. With image analysis and machine learning algorithms behind, it enables faster and cheaper land tenure information collection and minimizes field survey activities. The Publish and Share (PaS) cloud platform works based on the LADM, web-based application programming interface (API), and cloud services platform concepts. It enables land administration system developers to use or incorporate spatial references into land tenure registration and focus only on functionalities request rather than re-implementing solutions for common problems. According to the authors, the tools, and the cloud platform match well with the FFPLA aspects but with a few exceptions, which might be from the research participants' disparity in conceiving concepts and meanings of the FFPLA elements. They concluded that the tools, independently or combined, could be integrated into land administration workflows by the PaS platform to deliver reliable land information through geo-cloud web service facilities.

Naghavi et al. [64] developed a model for collecting volunteered geographic information (VGI) for tenure security use based on open-source architecture under the Spatial Data Infrastructure (SDI) policy with a primary focus on data accuracy issues. It gathers the land right information via the user-convenient public service interface and media, such as social media, GPS and mobile data, free and open-source applications, etc. Then it transforms the data into standard formats to maximize interoperability and connectivity.

The authors tested the model in Iran and found it promising to collect reliable geographic information with volunteer smartphones that meet the desired data quality. They proposed VGI for time and cost-effective gathering of land information without intensive training. However, it is required to motivate the volunteers for responsible and accurate parcel data collection.

As seen above, both FELA and FFPLA could be enhanced by innovative approaches and technologies. The FELA innovation pathway seeks a responsible and innovative approach to system updating and upgrading. FFPLA also encourages new technological advancements and developments to improve the spatial framework over time. Such emerging technologies are expected to meet the FELA pathways and FFPLA desirable qualities while lowering the investment and operating costs of land administration systems.

4.5. FELA and FFPLA Are Already Working Hand-in-Hand

The study identified the FFPLA fundamental framework key principles implementation practices that satisfy the FELA pathway goals (Table 5) and the characteristic elements (Table 6). A checklist is created based on [9,14] for ease of further comparison to identify the best implementation practices that satisfy the FFPLA fundamental framework key principles, and the FELA pathway goals in common.

Understanding the countries' responses to FFPLA key principles and FELA pathway goals provides insight into how both work together to build successful cost- and time-effective land administration systems. Table 7 shows the countries response to FFPLA key principles and FELA pathway goals.

Table 7. FFPLA and FELA implementation checklist based on [9,14].

FFPLA Core Framework/ FELA Pathway	**FFPLA Key Principle/ FELA Pathway Goals**	**FFPLA Implementing Countries**							
		Benin	**Colombia**	**Ghana**	**Kenya**	**Mozambique**	**Namibia**	**Nepal**	**Uganda**
Spatial	Visible (physical) boundaries rather than fixed boundaries	–	✓	✓	✓	✓	–	✓	✓
	Aerial/satellite imagery rather than field surveys	–	✓	✓	✓	✓	✓	✓	✓
	Accuracy relates to the purpose rather than technical standards	✓	✓	✓	✓	✓	✓	✓	✓
	Demands for updating/upgrading and ongoing improvement	✓	✓	✓	✓	✓	✓	✓	✓

Table 7. *Cont.*

FFPLA Core Framework/ FELA Pathway	FFPLA Key Principle/ FELA Pathway Goals	FFPLA Implementing Countries							
		Benin	Colombia	Ghana	Kenya	Mozambique	Namibia	Nepal	Uganda
Legal	A flexible framework designed along administrative lines.	✓	–	✓	✓	✓	✓	✓	✓
	A continuum of tenure rather than just individual ownership	✓	✓	✓	✓	–	✓	✓	✓
	Flexible recordation rather than only one register	✓	✓	✓	✓	✓	✓	✓	✓
	Ensuring gender equity for land and property rights.	✓	✓	✓	✓	✓	✓	✓	✓
Institutional	Good land governance rather than bureaucratic barriers	✓	–	–	–	✓	–	✓	✓
	Integrated institutional framework rather than sectorial silos	✓	✓	✓	✓	✓	✓	✓	✓
	Flexible ICT approach rather than high-end technology solutions	✓	–	✓	✓	✓	✓	✓	✓
	Transparent land information with easy and affordable access for all	✓	✓	✓	✓	✓	✓	✓	✓
Governance, Institutions, and Accountability	Accountability and transparency increased	✓	✓	✓	✓	✓	✓	✓	✓
Policy and Legal	Gender-responsive and inclusive of vulnerable groups	✓	✓	✓	✓	✓	✓	✓	✓
Financial	Affordable investments and economic returns assured	✓	✓	✓	✓	✓	✓	✓	✓
Data	Reliable data and service quality attained	✓	✓	✓	✓	✓	✓	✓	✓
Innovation	Responsible and innovation oriented	✓	✓	–	–	✓	–	✓	✓
Standards	Interoperability and integration supported	✓	✓	✓	✓	✓	✓	✓	–
Partnerships	Cooperation, partnerships, and participation leveraged	✓	✓	–	–	–	–	✓	✓
Capacity and Education	Capacity, capability, knowledge transfer and exchange attained	–	✓	–	–	✓	–	✓	✓
Advocacy and Awareness	National engagement and communication enhanced for effective land administration	–	✓	–	–	✓	–	✓	✓

5. Discussion

Studies show that significant FFPLA efforts existed, for example, in China, Vietnam, Ethiopia, and Rwanda, before the concept gained global attention [14]. Following the conception of the seven characteristic elements and the three fundamental frameworks, it gained worldwide attention. Nowadays, the practical implementation of FFPLA is rapidly expanding to broader areas of land administration, aiming toward achieving the desirable qualities and the core principles, as outlined in the guiding principles [14].

However, the review focused on the tenure security function of land administration and discussed the execution of the fundamental framework principles of FFPLA, attaining the FFPLA pathway goals (Table 5) and FFPLA characteristic elements (Table 6). This leads to the identification of the best FFPLA execution practices in different geographical and governmental settings across the globe, using a checklist derived from the FELA goals and the FFPLA fundamental framework principles (Table 7). The potential contribution of emerging conceptual and technical innovations for the successful execution of FFPLA is also discussed and proposed promising ones for enhancing the best implementation practices.

5.1. Mainstreamed Practices Addressed Fela Goals through of FFPLA Implementation

The FFPLA approach supports establishing a flexible, inclusive, participatory, affordable, reliable, attainable, and upgradeable land administration system. In one form or the other, these desirable qualities of the FFPLA approach are realized while implementing the key principles of the fundamental framework. Furthermore, fulfilling the FELA pathway goals—as an umbrella framework for effective land administration—would indicate success in achieving the FFPLA approach and its characteristic elements. Although the implementation strategy and purpose differ depending on the ground reality and feasibility, the widespread practices are summarized and discussed under the FELA pathway goals.

- **Goal one: Transparency and accountability exercised**

The FELA target for increased transparency and accountability in land administration is relevant to the key principles of the FFPLA institutional framework. Uganda, Nepal, and Benin have implemented institutional coordination with all partners along the chain and clear responsibilities at various levels for transparent land rights registration and service delivery. Nepal further employed the STDM and established an integrated system for instant updates of the local judicial committee decisions on disputes. Mozambique followed a decentralized approach implemented through top-down and bottom-up (national to local, and vice versa) institutional integration with public participation. Appropriate land institutions were participating in the Colombian FFPLA pilot study. Kenya, Ghana, and Namibia engaged in formal and informal (customary and statutory) land sectors. However, the countries failed to avoid bureaucratic procedures for the reliance on chiefs and local authorities (Kenya and Ghana) and statutory requirements (Namibia) for issuing land-holding titles.

- **Goal two: Gender-responsive and inclusive of vulnerable groups enhanced**

The FFPLA implementing countries legalized the available forms of tenure and social equity for land rights, which allowed them to achieve gender-responsive and vulnerable-group inclusive land rights. Benin, Ghana, Kenya, Nepal, Namibia, and Uganda registered all tenure types accordingly. Mozambique purposely focused only on customary and good-faith occupation tenure registration. Colombia registered normal rights only, although the approach permits capturing all sorts of people-to-land relationships. Regarding inclusive registration of all social dimensions, Nepal and Uganda recognized the issue of gender and marginalized people having equitable access to land. Colombia, Ghana, Kenya, and Namibia acknowledged equal participation of men and women in land rights registrations. In Benin and Mozambique, women and vulnerable groups were oriented toward their land rights, even claiming their rights without fear of reprisal from their social group.

- **Goal three: Affordable investments and economic returns considered**

A hybrid of modern and traditional technologies, simple field survey techniques, and parcel-value-based charges are utilized for affordable investment and expense revenue while registering property rights. The countries also exercised flexible spatial accuracy and on-demand spatial data update/upgrade to minimize the FFPLA approach implementation costs. The prevailing practices also include legalizing the fit-for-purpose data collected by different techniques. Colombia, Ghana, Kenya, Mozambique, Nepal, and Uganda used aerial/satellite imagery to extract general/visible parcel boundaries, a less expensive technique than field surveys and require far less time and capacity. In Nepal and Uganda, simple field survey such as tape measurement, approximations, and smartphone applications are used to measure boundary lines. The approach also allowed for precise field surveys and equipment if a fixed boundary determination is required, with the parties covering the associated costs, as practiced in Benin and Namibia.

- **Goal four: Reliable data and service quality implemented**

Participatory and flexible spatial data collection and dispute resolution approaches are applied to meet the FELA goal of reliable data and service quality. Landowners and local land committee members participate in the spatial data collection process in all countries (Benin, Colombia, Ghana, Kenya, Mozambique, Namibia, Nepal, and Uganda), trained and supervised by qualified surveyors. The participants verified the field survey and adjudication results and the registration and certification of land use rights. Nepal further proposed legal amendments to the institutional arrangement to accommodate the process of spatial data acquisition. The FFPLA legal framework proposed a flexible and affordable approach for resolving land disputes and possible conflicts by delegated local administrative institutions (sector and district). Accordingly, Benin, Namibia, Nepal, Ghana, Kenya, and Uganda decentralized the land administration to local levels, thereby enabling the settlement of land disputes and potential confrontations. Mozambique enhanced the traditional judicial procedure for securing land rights and established a system at the provincial level to carry out the registration process.

- **Goal five: Responsible and innovation introduced**

Different innovative tools and techniques are employed for parcel data collection, processing, and validation to update/upgrade the system. Mozambique developed less skill-demanding mobile and cloud technologies for participatory identification of the spatial boundaries of land parcels. Uganda collected and stored land rights data using an innovative recordation tool (Sola Open Tenure and CRISP). Nepal used an innovative data model and mapping standards for data collection and system administration at the local level, which could be expanded to the national level. Benin and Namibia used GNSS-integrated smartphones to collect cadastral parcel data. Colombia implemented an advanced positioning service (RTX enabled GNSS) for spatial data collection and the commercial ESRI's Collector app.

- **Goal six: Interoperability and integration practiced**

Internationally agreed standards support interoperability and integration goal of FELA. In this regard, Benin and Mozambique have employed the ISO-endorsed Land LADM to develop the land administration system. Ghana, Kenya, Namibia, and Nepal utilized the STDM for an improved continuum of tenure security.

- **Goal seven: Cooperation, partnerships, and participation encouraged**

Few countries achieved this goal through fortifying partnership support and collaboration, engaging partners in organizing and providing awareness and capacity-building activities (Benin), and capacitating land institutions of the local governments (Uganda and Nepal).

- **Goal eight: Capacity, capability, knowledge transfer and exchange attained**

The FFPLA approach recommends strategies and activities for capacity development and knowledge transfer as required in the FELA capacity and education pathway. Consequently, Colombia, Mozambique, Uganda, and Nepal carried out awareness and capacity-building programs. Mozambique trained selected community members to capacitate the registration team. Uganda provided training based on an identified gap to enable local land administration assistants. Nepal capacitated grassroots surveyors in mapping with the STDM quickly.

- **Goal nine: National engagement and communication improved**

The FELA advocacy and awareness pathway goal targets national engagement and communication. It could be achieved through different advocacy and knowledge-sharing activities, as suggested in the FFPLA approach. Accordingly, Mozambique employed role-play training to educate the community about gender equality principles in land rights. Colombia and Nepal also provided awareness programs to the community to provide reliable and quality datasets. Uganda conducted an extensive public information and communication campaign through accessible media and public meetings.

As seen above, FFPLA-implementing countries have mainstreamed the FFPLA approach into their legal, spatial, and institutional frameworks. The analysis also proves that the FELA overall goals are well incorporated and achieved through the FFPLA implementation principles. The FELA strategic pathways could help countries structure specific strategies for effective land administration, much as the FFPLA guidelines enabled the development of country-specific strategies for FFPLA execution.

5.2. Jointly Pursued FELA Pathways and FFPLA Elements, Principles and Frameworks Provide Best Global Practices

The term "best practice" is used in various disciplines for improving practices based on proven performance [65]. According to the Merriam Webster dictionary [66], best practice is "a procedure that has been shown by research and experience to produce optimal results, and that is established or proposed as a standard suitable for widespread adoption". For the improved performance of peer projects, best practices provide a guiding framework to implement innovative and replicable experiences of others [67].

The combined success story of the FFPLA key principles and the FELA pathway goals is projected to deliver global best, (or successful) FFPLA implementation practices, as envisaged in the methodology section of the study. As a result, the FFPLA implementation practice in Benin, Colombia, Ghana, Kenya, Mozambique, Namibia, Nepal, and Uganda achieved all or the majority of the FFPLA key principles and the FELA pathway goals. However, the implementation approaches could differ from one country to the other.

In Nepal, FFPLA implementation is satisfactory; the fundamental framework key principles are well implemented, and the FELA pathway goals are achieved. Uganda has likewise successfully implemented FFPLA, but there is little proof of the adopted interoperability and integration standards. The practice in Mozambique satisfied all requirements but was not inclusive in registering all tenure types. It also lacks clearly defined ways for strengthening partnerships and supporting collaboration. Benin did not apply the visible boundary and use of aerial/satellite imagery. In addition, it has no experience in knowledge transfer and awareness-creation for effective land administration. Colombia has met the FELA pathway goals. However, it failed to prove institutional integration for recording and registering land rights by delegated local land authorities. The approach does not prove the absence of bureaucratic barriers. It also employed high-end technology solutions rather than a flexible ICT approach.

Ghana, Kenya, and Namibia have similar stories of meeting the FFPLA key principles and FELA pathway goals. The countries failed to realize good land governance in rural and peri-urban areas, for there is a dependency on local chiefs and authorities (Ghana and Kenya) and extraneous legislative requirements (Namibia) to deliver land-holding titles. Namibia employed a fixed boundary approach, contravening the FFPLA visible boundary key principle. The countries also do not have shared experience in partners' engagement, advocacy and awareness activities, and capacity-building initiatives.

5.3. Emerging Innovations, Enhancing the Best Practices

Conceptual innovations enhance the successful implementation of FFPLA for a broader range of land administration functions. With the advancement of computing technology and geospatial information demand growth, innovative ideas are emerging and becoming available at the implementation and study level. The innovations are appealing for efficient FFPLA execution to realize tenure security for all, as suggested in the SDGs. However, employing these emerging geospatial technologies in land administration could be capacity-demanding. It would be beneficial to assess in advance the likelihood of successful implementation. A framework developed by Tan et al. [62] could provide insight to examine and identify the available and necessary skills and capacity for implementing the technologies.

Furthermore, while it may need to be aligned with existing ground realities, the innovations are adaptable and applicable to developing countries' tenure security challenges. The analytical model by Bennett et al. [20] could be employed to identify maintenance issues and propose suitable solutions for the highly dynamic peri-urban land administration update/upgrade issues.

The conceptual development of a new public-private partnership (PPP) could secure the funding for establishing and maintaining the land administration. It would maximize the government's commitment to fostering a favorable political climate and the private sector's involvement in land security and enhanced service delivery. The PPP model could involve many private enterprises (real estate companies, agricultural firms, industrial zones, etc.) to financially secure the services rendered by peri-urban land administration for mutual benefit. However, Organizations need to have the appropriate capacity and experience in contract management to successfully design and manage a PPP.

Emerging geospatial tools are providing feasible and extensible solutions as an alternative to the time-and cost-intensive conventional surveying fieldwork for cadastral data collection. The automatic boundary delineator could generate parcel boundaries with acceptable accuracy. SmartSkeMa can be applied for community-based land tenure documentation. The Publish and Share (PaS) cloud platform facilitates land administration system development by offering high-level geocloud-based services. The Volunteered Geographic Information (VGI) model agreed with the FFPLA requirement for engaging the public and private sectors in establishing a geospatial data sharing and publishing platform.

6. Conclusions and Recommendations

The study reviewed 19 articles concerning FFPLA practical implementations and conceptual innovations in 15 countries to identify best practices that could be customized and extended to other land administration settings. Most of the reviewed articles are published in the land journal special issues in 2021 and are concerned about conceptual innovations (Volume I) and practical FFPLA implementations (Volume II) across the globe. Three recent articles from the Land Use Policy Journal are also included. The study employed the FFPLA fundamental framework key principles and FELA pathway goals to characterize the best implementation approach.

According to the study, countries have successfully mainstreamed FFPLA implementation practices into their institutional, legal, and physical frameworks. Even though the FFPLA approach was developed before the FELA Framework, the FFPLA principles and guidelines are well aligned with the FELA goals and pathways. The actual implementation of the FFPLA approach and the FELA goals eventually depend on the country's context in terms of institutional settings and available capacity. Jointly pursuing FELA and FFPLA could provide best implementation practices that inform approaches for future FFPLA projects. The contribution of emerging geospatial innovations is also promising for efficacious execution of FELA and FFPLA.

From recent FFPLA executions covered in the review, the implementation practice in Nepal is identified as the best practice, for it successfully executed the FFPLA fundamental framework key principles and satisfied the FELA pathway goals. The FFPLA implementations in Uganda, Mozambique, and Benin were also successful and possessed experiences which could be expanded to other countries.

Emerging technical and conceptual innovations are providing promising results, enhancing the cost and time effectiveness of the FFPLA approach. The analytical maintenance model could solve the missing update/upgrade issues in the land administration practices. The public-private partnership (PPP) model is an innovative concept to secure funding for land administration initiatives. The auto-boundary delineator application and the VGI model could be a technical alternative for time and resource consuming surveying fieldwork. SmartSkeMa can be applied for community-based land tenure documentation.

The best FFPLA practices and innovations identified in the study could be customized and extended to other land administration settings, such as peri-urban areas where urbanization is intense. The translation of FELA into Spanish, French, Arabic, Dutch, and Mandarin [18] further helps FFPLA as an implementation tool, get more worldwide recognition. However, Tan et al. [62] suggested a detailed examination of the FFPLA fundamental framework core principles and capacity of the implementing countries for large-scale implementation and technical feasibility. Further research is recommended to evaluate the efficacy, practicability, innovativeness, transferability, and model character of the best practice for spreading it to other land administration contexts, as stated in [67]. A socio-economic impact assessment is also advisable to justify and strengthen the business case for adopting FFPLA. It is a helpful tool to maximize positive benefits that contribute to sustainable development [68].

Nonetheless, it has to be noted that the best FFPLA implementation practice is identified based on the limited information available in the reviewed articles. There could be more studies and implementation practices that do not appear in scientific journals. FFPLA implementation practice and conceptual innovation supported by financial and aid organizations such as the WB, UNHABITAT, GLTN, FAO, etc., could also provide further insights. Project based searches need to be considered for more successful FFPLA innovations and implementation practices. Thus, since the result is formulated based on the journal articles accessed for the study, it does not either judge the various countries' experiences as insignificant or ignore FFPLA efforts in different situations. Furthermore, following each thriving implementation practice, the willingness and engagement of the governments have to be acknowledged.

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Notes

1 PRISMA is an evidence-based minimum set of items for reporting in systematic reviews and meta-analyses (https://prisma-statement.org/; accessed on 9 January 2022).

2 Barbados Jamaica, Saint Lucia, and Trinidad and Tobago are the Caribbean Islands covered in the study.

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Article

Land Administration As-A-Service: Relevance, Applications, and Models

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Abstract: The 'as-a-Service' (aaS) concept of the IT sector is suggested to reduce upfront and ongoing costs, enable easier scaling, and make for simpler system upgrades. The concept is explored in relation to the domain of land administration, with a view to examining its relevance, application, and potential adaptation. Specifically, these aspects are analysed against the long-standing problem of land administration system maintenance. Two discrete literature reviews, a comparative analysis, and final modelling work constitute the research design. Of the 35 underlying land administration maintenance issues identified, aaS is found to directly respond to 15, indirectly support another 15, and provide no immediate benefit to 5. Most prominent are the ability of aaS to support issues relating to financial sustainability, continuous innovation, and human capacity provision. The approach is found to be already in use in various country contexts. It is articulated by the UNECE as one of four scenarios for future land administration development. In terms of adaptation, the 4-tier framework from Enterprise Architecture—consisting of Business, Application, Information, and Technology layers—is used to model and describe five specific aaS approaches: (i) On Premises; (ii) Basic Outsourcing; (iii) Public Private Partnership; (iv) Fully Privatised; and (v) Subscription. Several are more theoretical in nature but may see future adoption. Each requires further development, including case analyses, to support more detailed definitions of the required underlying legal frameworks, financial models, partnerships arrangements, data responsibilities, and so on. Decisions on the appropriate aaS model, and the application of aaS more generally, are entirely dependent on the specific country context. Overall, this work provides a platform for land administration researchers and practitioners to analyse the relevance and implementation options of the aaS concept.

Keywords: cadastre; land registration; information systems; SaaS; PPPs; FELA

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1. Introduction

The concept of 'as-a-Service' [1] (aaS) is a well-founded approach in the domains of information technology (IT) and information systems (IS). It suggests a movement away from business and organisational models focused on delivering products at repeated and often ad hoc intervals, towards a service-oriented subscriber model [2]. Many traditional providers of IT software and hardware have moved towards the model, and it finds increasing use across other sectors [3]. The aaS approach is suggested to minimise upfront costs, reduce ongoing costs, enable easier scaling, and make system upgrades simpler.

The aaS model deserves consideration in the land administration domain, particularly in relation to the significant and longstanding problem of land administration system maintenance [4]. A land administration system collects, manages, and disseminates information, spatial and social in nature, about land tenure, land value, land use, and land development. In this work, the term 'land administration' is considered to encompass the terms 'cadastre' and 'land registry'. In many country contexts, significant effort is afforded to securing initial funding and establishment of land administration systems; however, far less attention is given to ensuring the system is self-sustaining [5]. The result is that data in the system becomes outdated or parts of the system decay over time, resulting in wasted investment.

The concept of maintenance encompasses the updating of a land administration system with changes to people-to-land relationships (e.g., transactions), or the upgrading of data quality within the land information system in terms of accuracy of content, or the broader renewal of its underpinning IT infrastructure [6,7]. Whilst there exists a significant amount of literature on approaches to improve maintenance, e.g., [4,8,9] problems continue to persist in practice, e.g., [10].

Fundamentally, some of these problems are macro in nature, for example, relating to broader issues of public trust in government institutions, and may not be within the immediate gambit of land administration practitioners to solve outright [4]. However, where appropriate, practitioners should continue to explore alternative administrative approaches, particularly those developed in similar or related disciplines, such as public administration or IT. In this regard, it is the role of applied scientific domains to explore and report on these developments.

Therefore, to move the discourse beyond mere understanding of the 'maintenance' challenge and acknowledge recent work from the UNECE on scenario development for future land administration design c.f., [11], this paper explores the idea of applying the aaS approach to mitigate, transfer, or remove the maintenance problem. It should be noted that very few examples of published, independent, critical, and structured academic works exist linking aaS and land administration. A preliminary review of online academic literature repositories conducted as part of this work (see Section 6), combining aaS and land administration keywords, revealed only a handful of papers directly linking the concepts.

The overarching aim is to undertake a critical exploration of the aaS concept in terms of relevance, application, and potential adaptation to the domain of land administration, and specifically maintenance. The results can provide a platform upon which land administration practitioners and researchers can assess, pilot, and refine the approach.

After this introduction section (Section 1), an overview of the applied methodology is provided in Section 2. A 4-step research design is described. It consists of two separate literature reviews (one on the 'land administration maintenance' problem and the other on the aaS solution); a comparison of the outputs of these reviews; and a final fusion or synthesis phase. The results of each step are presented independently in Sections 3–7. An overall preliminary understanding of the relevance and utility of aaS is arrived at in Section 8, the conclusion section, which provides an overarching summary and suggested areas for further work, for both practical and research domains.

2. Materials and Methods

This work sits within the pragmatist research paradigm, closely linked to design or engineering research. That is, this work seeks to assess whether the aaS conceptual solution has validity for the domain of land administration, and if so, how it might be adapted or implemented within the domain.

There exists minimal works directly linking the aaS and land administration concepts (see Section 1, Introduction). Therefore, rather than undertaking or reporting on specific pilot studies or cases, this work must begin first from principles to identify foundational concepts on aaS and land administration maintenance, sitting in disparate bodies of academic literature, and then seek to combine those concepts. For this, the methodology of 'research synthesis' [12] is used. This involves setting the bounds around a relevant body of literature, reviewing it in a structured fashion, and assembling the findings to form a novel contribution. The approach is used widely across many domains, including land administration, with justification and specific examples provided in [4,13–18]. In the context of this work, it needs to be noted that the research synthesis methodology is limited in that it only captures published applications and cases. Other applications of aaS linked to land administration may exist in practice. Therefore, whilst the body of analysed literature may be considered comprehensive, it may not reflect all applications occurring within the sector. That said, this work may act as inspiration to empirically capture other cases of aaS application.

For this work, two overarching components exist with regards to the exploration: (i) relevance and (ii) application and/or adaptation. To use the method of research synthesis to achieve the demands of the 2 components, a research design of 4 interlinked steps was conceived (Figure 1). This was because, as already mentioned above, there exists very few works directly linking the aaS and land administration concepts. Therefore, the two previously disparate bodies of literature were first analysed in terms of maintenance problems and aaS solutions (Step 1 and 2). This enabled a comparative analysis of problems against solutions (Step 3), and finally synthesis/modelling (4). The 2 bodies can be described as 'land administration maintenance' on the one hand, and 'aaS' on the other. The process for reviewing each body is first explained, and then the comparison and fusion processes are outlined.

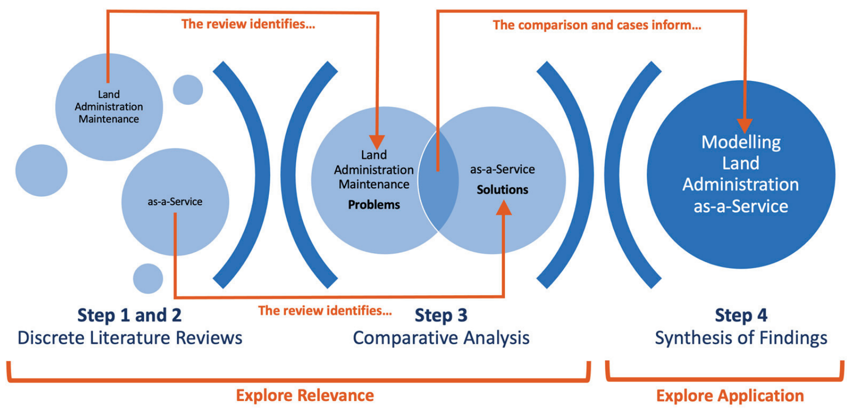

Figure 1. Research Workflow.

The 'land administration maintenance' review (Step 1) work is presented in [4]. The literature search and review procedure are fully presented in that work. In summary, (i) a review period between January 1990 and December 2020 was justified; (ii) searchable repositories included Scopus, Science Direct, Google Scholar, the OICRF website (International Office of Cadastre and Land Records), and standard Google searches (i.e., to enable incorporation of relevant grey literature); (iii) search strings and combinations included 'maintenance', 'update', 'upgrade', 'renewal', 'land administration', 'cadastre', 'land registry' and 'fit for purpose'; (iv) snowballing [4] determined the constellation of relevant papers; and (v) analysis and reporting were chronological. The summarised results of [4], *relevant to this work*, are presented in Section 3. These include a contemporary definition and a categorisation of the major problems relating to land administration maintenance.

For the aaS review (Step 2), a similar process was undertaken. The concept is newer than the land administration maintenance issue, with initial searches suggesting it originates in the mid-2000s. As such, to ensure completeness, the epoch January 2000 to December 2020 was initially selected. The same search repositories were utilised as per the 'maintenance' search. The aaS concept is a cross-cutting or cross-disciplinary concept, and for this review all aspects of the concept were considered relevant; the search repository approach enabled this cross-disciplinary analysis of the literature. Search terms included 'as a Service' and 'aaS' and extensions such as: 'Software as a Service' or 'Saas'; 'Infrastructure as a Service' or 'Iaas'; 'Data as a Service' or 'DaaS'; and 'Everything as a Service' or 'EaaS'. As mentioned, these terms were also searched in combination with land administration terms (i.e., registry, cadastre), and 'government services' more generally, to identify any pre-existing work on overlaps in the domain. Similar to the 'land administration maintenance' concept, the results were first analysed and reported chronologically. Special attention was made in this analysis to identify the key characteristics of what constitutes aaS from business, management, and technical viewpoints. Additionally focused upon were enabling conditions, advantages, and disadvantages of aaS. The results of the review are presented in Section 4, covering the definition, drivers, designs, the problems aaS intended to solve, and the benefits of aaS. The aaS is outlined as a theory and model, and state-of-play examples from other sectors are provided.

To complete the 'relevance' exploration, a comparative analysis (Step 3) was undertaken. Key features of the aaS solution were logically mapped against the 'maintenance' problems, as identified in [4]. The mapping involved using the results of both literature reviews from Step 1 and 2, making direct comparison between problem and solution, and identifying the benefits of aaS against the problems of land administration maintenance. Identified were the major challenges and opportunities relating to land administration maintenance, against the characteristics, enabling conditions, benefits, and disadvantages of aaS. Essentially, this provided an initial overview, if not suitability assessment, of the potential utility of aaS in land administration, and specifically in response to maintenance problems. The results are presented in Section 5.

For the exploration of 'application' (Step 4), the results were compiled descriptively. Inputs included results from Step 1–3, and analysis of any further literature identified already demonstrating efforts to combine land administration and aaS. The results are presented in Section 6. The analysis then more deeply considered the potential application of aaS in the context of land administration in terms of contextual requirements, potential benefits realisation, and probable implementation challenges. These results are presented in Section 7. Use was made of the existing models of aaS to guide the analysis. This modelling work also led to the identification of further research in terms of (i) further confirming the findings and refining the characteristics and requirements of each of the aaS models via more nuanced case studies on specific land administration systems, and (ii) piloting and assessing the approaches within a jurisdiction. The results of this work are presented in Section 8.

3. Recapping the Maintenance Problem

A contemporary overview of the maintenance problem (Step 1), along with attempts to understand it and suggested solutions, is provided in [4]. The review covers over 100 academic works from over a 70-year period, although primarily since 1990. An overview of the key findings relevant to the aaS analysis is now provided.

First, the review demonstrated that the land administration maintenance problem is long documented. In the 1970s–1980s, maintenance challenges were heavily motivated by the first forays into moving from paper-based manual systems to digital and automated systems. In the 1990s maintenance appears to have been a secondary concern to system establishment, particularly in post-Communist and emerging economy contexts. The 2000s placed more focus on 'systems' and 'socio-technical' understandings, although again, maintenance appears to have been a secondary concern. From the 2010s onwards, in the so-called 'fit-for-purpose' era, a more concerted focus on maintenance was apparent. That said, scaled implementations of fit-for-purpose applications were still seen to be struggling with ensuring adequate maintenance.

Second, the review meaningfully disaggregated the problem into several sub-elements (Figure 2). It defined key terminology and demonstrated the essential differences between those terms. In this regard, it revealed the potential for erroneous debates, whereby practitioners discuss different parts of the same broader conceptual problem. The disparity between 'upgrade' and 'update' provides a prominent example. The different challenges for 'spatial' versus 'rights' data updates provide another. Essentially, there is a clear need to distinguish between the day-to-day challenges of updating data, versus the longer-term strategic challenge of renewing entire systems. The latter is more likely to include aspects of institutional change, potential legal reform, and new financial models, alongside technology upgrades. The resulting taxonomy of maintenance problems assists in system diagnostics and resultant solution development. The framework can provide utility in the exploration of the aaS approach.

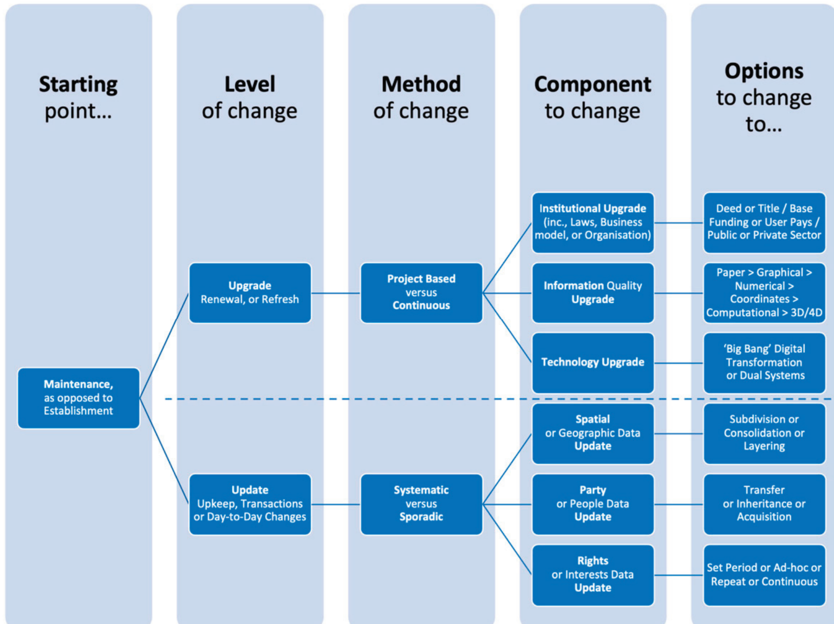

Figure 2. The overarching maintenance problem is an aggregation of many aspects and various terminology (source: [4]).

Third, the review also delivered an organising framework for the broad suite of solutions for maintenance issues. Here, use was made of the Framework for Effective Land Administration (FELA) report made available by the Expert Group on Land Administration and Management as part of the work of the United National Committee of Experts on Geospatial Information Management (UNGGIM) [19]. Solutions (and problems) relating to maintenance were classified under the following categories: (i) Governance and Institutions; (ii) Law and Policy; (iii) Financial; (iv) Data and Processes; (v) Innovation; (vi) Standards; (vii) Partnerships; (viii) Capacity and Education; and (ix) Communications and Awareness. The catalogue could assist in problem diagnosis of the 'as is' situation, but equally and more importantly, assist in the identification and selection of both responsible and fit-for-purpose 'to be' solutions. Again, the model's utility in understanding the applicability of the aaS approach is clear.

Fourth and finally, the review made clear that both the problem and solution spaces are dynamic and ongoing attention needed to be afforded to emerging trends. This included going beyond the land administration domain to identify new developments, be they related to institutions, law, finances, or technology, amongst others, or combinations of those. Developments relating to automatic feature extraction, cloud services, and cybersecurity concerns are mentioned. In this vein, the review justifies considering the aaS approach in the land administration domain, although it does not mention aaS specifically.

4. Unpacking 'as a Service'

Step 2 results revealed that the origins of the aaS concept, at least in the broad domain of IT, dates at least to the 1980s and 1990s. The author of [20] outlines the benefits and costs of the approach with regards to bug fixes, while [21] introduce the 'Software Service System' as a means of enhancing software use and marketing, outlining the need for supportive fee payment and IP management approaches. Further, [22] argues that issues of cost overruns and delay relating to software provision are due to the 'product' mentality, stemming from hardware provision, used in the industry. However, it was really in the late 1990s, due to the exponential growth and uptake of the internet and IT outsourcing [23], that the software aaS concept gained more use and acceptance as a viable business and operational model, at least in terms of future industry development [24,25]. The general idea was that rather than paying for software as a product, at ad hoc moments and based on unpredictable market demands or opportunities, a business could enter a subscription service with a software provider, pay a regular fee or license, and receive ongoing enhancements and updates. The approach would have the dual benefits of ensuring a more regular income stream for software vendors, whilst also assisting in overcoming the persistent challenges of maintaining outdated software versions and software piracy, amongst others.

By 2008 the concept had mainstreamed: the 'SaaS' acronym had wide use across the IT industry as an exemplar service delivery method, being contrasted to COTS (commercial off-the-shelf software) [26], and with SOA (Service Oriented Architecture) acting as the commensurate software design approach [27]. The implications of the approach were examined from the business model, technical integration, and customer perspectives [28,29], amongst many others [30,31]. By 2010, the perhaps more marketer-friendly 'cloud' terminology (i.e., including 'web services') had somewhat overtaken aaS in mainstream software marketing, as optic-fibre cable networks, if not prolific Wi-Fi networks, and low-cost data storage, enabled the realisation of higher bandwidth internet services [32].

From 2010 onwards, the aaS moniker was transferred across all parts of the IT spectrum, spawning 'Data as a Service' (DaaS) [33][1], 'Infrastructure as a Service' (IaaS), 'Platform as a Service' (PaaS) [34], and the somewhat less useful 'Everything as a Service' (EaaS) [35], or 'Anything as a Service' (XaaS).

The approach also proliferated in mainstream consumer markets with the extension of the internet service provider (ISP) subscription model, usually based on a monthly fee, which translated successfully into the media and entertainment domains, thanks to Web 2.0, most prominently including services such as Spotify, Apple Music, Amazon Prime, and Netflix, and the mobility market (e.g., Uber One or Uber Pass). The impact aaS might have on transportation and the disruptive socio-economic flow on effects were explored [36] (i.e., MaaS). Whilst the approach's benefits were espoused, the socio-technical challenges of ensuring privacy, security, independence, and service quality also received attention [37].

Going even further, the potential adaptation of aaS was explored in the areas of machine learning (i.e., Machine Learning as a Service, or MLaaS) [38], and for evaluation of systems more generally (i.e., Evaluation as a Service, or EvaaS) [39]. At this point, one might question whether the term had merely become an overused—but presumably highly effective term for marketing departments—or whether the term had even been hijacked for pushing underlying political, if not philosophical, agendas. A well-known example of the latter is the World Economic Forum's '8 predictions for the world in 2030,' published in 2016[2], with one prediction being, "You'll own nothing, and you'll be happy," with the explanatory text going on to outline that by 2030 most individual needs would be provided as services, not as conventionally purchased products.

With the background development of aaS now provided, for the purposes of this study it is necessary to confirm what constitutes aaS in terms of definition, scope, and components. At the broadest level, the definition used here is: "something being presented to a customer, either internal or external, as a service" [40][3]. Interestingly, due to the broad use of the term across multiple disciplines and the mainstream, finding and selecting a standardised analytical framework for aaS is a somewhat fraught exercise. As shown above, it could variously include a focus or components on business model aspects, technology aspects, legal/policy issues, partnership approaches, concerns about data and standards, security aspects, service level agreements (SLAs), and so on. In terms of conceptual models, a large proportion of diagrams are simple infographic-like depictions with rudimentary, if not ill-explained, linkages between system components. Another common and perhaps more useful approach is to differentiate SaaS, IaaS, PaaS, and other 'aaS' by means of continuum[4]. These are usually technology-centric depictions illustrating the technologies and tasks the client organisation is responsible for, and those for which the service provider organisation is responsible. However, these are more focused on business-to-business or government-to-government aaS service arrangements, and tend not to include the customer or citizen in terms of their responsibilities and technology requirements.

Taking the above into consideration, it is suggested that modelling approaches from the sub-domain of 'Enterprise Architecture' (EA) and 'SOA' provide a basis for aaS analysis [27,41]. EA forms the conceptual basis of many Enterprise Resource Planning (ERP) software implementations (e.g., using Oracle, Intuit, or Workday platforms) within organisations, with 2nd generation cloud-based ERPs c.f., [27–32] often themselves referred to as SaaS [42]. The EA concept is also known to the land administration domain, via the use of ERPs and Enterprise Geographical Information Systems (GIS) [43]. The underlying EA frameworks that support ERP implementations promote a whole-of-organisation (if not a whole-of-inter-organisational) approach and combine business aspects with technology aspects when it comes to managing the data and processes of an organisation.

Most of these EA frameworks include (at least) four (4) key layers: business, application, information, and technology. The business context includes the mandate to operate along with legal, organisational, and financing aspects. The application context includes the interfaces, transactions, or services undertaken with customers to enable delivery of their business needs. The information architecture includes the data, standards, and processes used to support the applications. The technology layers include the technology, hardware, and networks needed to capture, store, and disseminate information flows.

Applying aaS to this 4-layer framework, the different aaS models can be seen as on a continuum of transfer-of-responsibility, whereby there is a movement from full-on premises hosting and responsibility towards IaaS (where technology is off-site/sourced), to PaaS (information and databases are also offsite/outsourced), and finally to SaaS (applications also outsourced) (Figure 3). The most appropriate model depends on the business context, considering the level of internal control desired and IT costs allocated. This is where appropriate design decisions and responsible implementations are needed. It should be noted that there are countless versions and variations of Figure 3 available, differing in the number of layers to manage and the variety of aaS models. Here, a highly simplified version is presented for illustrative purposes.

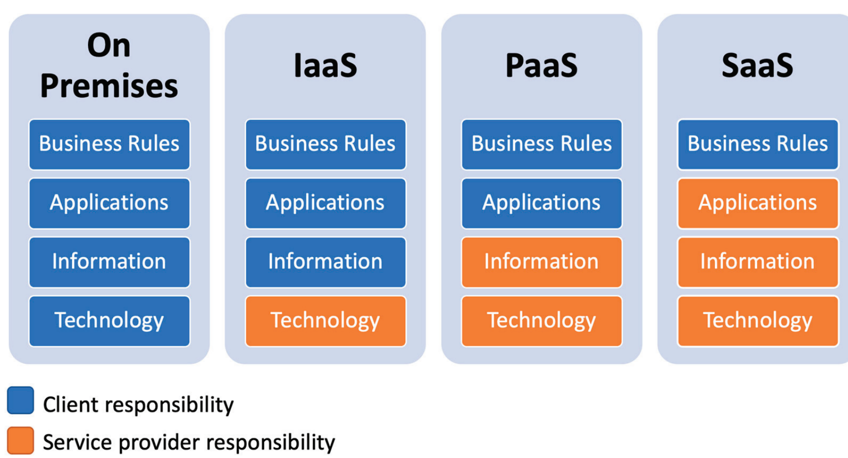

Figure 3. Common depiction of aaS with respect to EA layers (adapted from: https://www.redhat.com/en/topics/cloud-computing/what-is-saas, accessed on 12 January 2023).

In terms of the benefits aaS delivers or the problems it can support solving, summarising the above works, figures and [44], the following can be stated: (i) lower upfront costs; (ii) shorter lead times to initial benefit realisation; (iii) smaller on-going costs (on account of a shared or multi-tenant hosting environment); (iv) access to business-critical applications anytime and anywhere (thanks to the cloud-based nature of aaS); (v) more straight-forward modification, tailoring, and updating of set processes; (vi) easier scaling of systems and cleaner integration of systems; (vii) improved or more responsive real-time support; (viii) simpler piloting and proof-of-concept delivery; (ix) great ability to introduce significant upgrades (i.e., paced and iterative); and (x) system redundancy, backup, and upgrading benefits.

Having provided an outline of aaS in terms of origins, definitions, components, and benefits, the subsequent section undertakes a comparison with direct reference to the land administration maintenance challenge.

5. Comparing for Relevance

The results of the comparative analysis (Step 3), based on the inputs of Step 1 and Step 2, are presented in Table 1. Here, an adapted version of Table 1 in [4] is used to present the comparison. It directly links the maintenance problems and the aaS solution. The specific problems relating to land administration maintenance are categorised under the 9 strategic pathways of FELA. In turn, the ability of the supposed benefits aaS to respond to those problems is assessed. Initially, this is presented as a simple 3-point Likert scale indicating whether aaS could provide direct response (D); indirect response (I) (i.e., a flow-on benefit or side effect of an aaS intervention); or no or limited response (N) to the specific maintenance problems. Whilst these indicators are considered self-explanatory, they are then further explained and justified with a textual description in the final column.

Table 1. Overview of land administration maintenance challenges and potential responses of aaS (adapted and updated from [4]; Note: D = direct response; I = indirect response; N = no or limited response).

FELA Strategic Pathway	Maintenance Problems (Adapted from [4])	aaS Response	Explanation (Stemming from [20–42])
1. Governance and Institutions	Land agencies have project focus rather than continuous improvement focus.	D	aaS enables continuous improvement, provided it is embedded in the relevant SLA.
	Land agencies only have a mandate for establishment (i.e., no clear mandate for upgrades exists).	N	On its own aaS does not establish mandates for upgrades, although it can help clarify roles.
	Land agency organisational resistance to upgrades from within, and external stakeholders.	D	aaS results in reallocation of upgrade mandates and incentives to external land sector actors.
	Conventions and traditions guide processes.	I	aaS demands a rethink of conventions and traditions.
2. Law and Policy	No developed adopted policy on updates or upgrades.	I	aaS might be part of a whole-of-jurisdiction policy development process for land administration.
	Failure to create laws for updating and/or upgrading.	I	aaS prioritizes moving towards digital data over paper in policy/law, and might be part of specific legal reforms on outdated legislation/regulations.
	Regulations for data capture are outdated or prescriptive.	I	aaS can support deregulation of maintenance requirements and actors involved.
	Implementation and enforcement of laws is not in place.	N	aaS does not ensure legal implementation and enforcement on its own.

Table 1. *Cont.*

FELA Strategic Pathway	Maintenance Problems (Adapted from [4])	aaS Response	Explanation (Stemming from [20–42])
3. Finances	Funding dependencies on allocated government budget (i.e., not self-sustaining).	N	aaS does not necessarily change underlying funding structures.
	Existing business models result in government losses.	D	aaS helps to reduce upfront and ongoing costs, and may result in new business model (e.g., pay-per use, yearly fees, subscription).
	Land agency 'rent seeking' behaviours.	D	aaS assists disrupting rent seeking behaviours by transferring responsibilities.
	Petty and/or grand corruption.	D	Digitalisation via aaS supports reduction in corrupt behaviours.
4. Data and Processes	Analog data persists across spatial and party data.	D	aaS implies move towards digitalisation, e.g., via a scanning/digitising partnerships, data model development, and digital cadastre development (inc. 3D).
	Transactions remain paper-based/manual.	D	aaS involves business process redesign, and a move towards digitalization.
	New transactions are not recorded.	I	aaS can mean more responsive and broader coverage of service provision.
	Spatial updates are not made at all.	I	aaS can result in more frequent spatial updates, and use of imagery, feature extraction, and 3D/4D.
	Lack of quality of control over data processes.	I	aaS introduction may be accompanied with improved quality control procedures.
5. Innovation	No innovation processes embedded to promote and enable change within land agencies.	D	aaS, via SLA, can assist embedding innovation and system renewal via continuous improvement.
	No promotion of entrepreneurship and/or innovation in the land sector.	D	aaS brings new actors into the land sector, fostering entrepreneurial acumen amongst land sector stakeholders, beyond land agencies.
	No existing IT infrastructure and/or technology blueprint.	D	aaS demands creation of IT infrastructure blueprint.
	Legacy IT infrastructure no longer supported.	D	aaS disrupts legacy IT infrastructure and can support development of parallel IT prototyping.
6. Standards	Lack of standards on initial capture and maintenance.	I	aaS may be part of broader introduction of technical and managerial standards (e.g., OGC and ISO).
	Quality control and enforcement issues, even where standards do exist.	I	aaS may include quality and enforcement aspects, via the SLA.

Table 1. *Cont.*

FELA Strategic Pathway	Maintenance Problems (Adapted from [4])	aaS Response	Explanation (Stemming from [20–42])
7. Partnerships	Failure to create and maintain partnership networks (local, national, international).	D	aaS demands a focus on partnership building programs and a portfolio approach.
	Lack of inter-organisational processes at business, semantic, information, or technology levels.	D	aaS forces review and renewal of inter-organizational processes via mapping and redesign.
	Dependencies on other data providers.	I	aaS provides opportunity to revisit data dependencies.
	Prevalence of data silos among land agencies.	I	aaS process may involve breakdown of data silos.
	Poorly constructed or enforced public private partnerships (PPPs).	I	aaS provides opportunity for renewal or review of PPPs (but also risks creating them).
8. Capacity and Education	Staff skills outdated or beneath required levels.	D	aaS makes more immediate availability of IT skills via service providers (although does not necessarily update internal skillsets).
	Educational curricula outdated in terms of theories, methods, and technologies.	N	aaS will not necessarily result in updating curricula, methods, and technologies in courses, although it could foster accreditation and professional development.
	Staff composition too static or too frequently changed.	D	aaS can enable or force staff restructures.
	Cross-border or cross-disciplinary 'brain-drain' in terms of IT/technical capacities.	I	aaS may further increase or decrease 'brain-drain' via outsourcing and offshoring.
9. Communications and Awareness	Trust and awareness levels in public institutions are low amongst citizens.	I	aaS service provider may bring status and recognition, supporting the land agency via association.
	No engagement with processes and public services.	I	As part of aaS, marketing and communications can be reformed or even outsourced.
	No formalised communication plan or channels.	N	aaS does not directly improve communication plans or channels, but can be part of broader reforms, e.g., local pop-ups or one-stop-shops.

In terms of quantitative results, of the 35 maintenance issues identified in [4], aaS is suggested to enable direct responses or support in 15 cases, indirect or flow-on support in 15 cases, and no immediate benefit or response in 5 cases. In terms of specific FELA pathways, 6 of the 9 pathway problems are found to directly benefit from the aaS solution. Most prominent are those problems relating to 3. Finances and 5. Innovation. Others directly benefiting include 1. Governance and Institutions, 4. Data and Processes, 7. Partnerships, and 8. Capacity and Training.

A level of caution is required when reviewing Table 1. The comparison is based on a broad definition of aaS. As shown in Section 4, it can have quite narrow IT-related or broader system or inter-organisational meanings. It is important to state that the aaS benefits are only *potential* benefits, and may as yet be unproven in land administration practice. In some cases, aaS interventions may not produce the desired benefits and may even exacerbate problems of maintenance. Additionally, the appointment of indicator values, whilst helpful in providing an overall assessment of the *potential* relevance of aaS, necessarily includes a level of subjectivity. Affirmation of these ascribed indicator values requires more data, quantitative or qualitative in nature, stemming from practical case examinations. As already mentioned in the Introduction (Section 1) and Materials and Methods (Section 2), limited in-depth published case applications exist, and the number of case applications in practice is unknown.

Limitations aside, the comparison suggests, as has been found in other sectors, that the aaS model may have utility in the land administration sector. That is, the results strongly suggest, at least from this initial overview, that aaS has high relevance. Accordingly, how (and whether) the aaS concept could be adapted and implemented in land administration practice is explored in the subsequent section.

6. Analysing Contemporary Applications

Until now, this work has not yet presented, at least in any detail, any pre-existing work exploring, applying, or combining the aaS and land administration concepts. As mentioned in Section 1 (Introduction), an initial structured search of online academic repositories, combining relevant aaS and land administration keywords returned very few relevant results (6). Within these, the aaS concept was often treated broadly, lacking specific definition, or a breakdown into analytical components. None of the papers dealt directly with an assessment of benefits and problems in relation to the land administration maintenance problem. That said, it is necessary to also examine these efforts at previous application within the domain. As already noted, beyond the preliminary search that motivated the work at hand, the relevant works also appeared again in Step 1 and Step 2 searches. To commence the aaS application exploration, the results are presented here.

Certainly, the concept of 'service' is well-known to land administration, land registration, and cadastres. As a somewhat invisible infrastructure (i.e., even boundary monuments are increasingly seen as redundant), surveyors and land administrators have long been at ease describing land administration as suites of 'services' rather than a distinct set of products [43–47]. In this regard, the era of digitalisation and its accompanying language has found much resonance in the domain. Even the advent of FFPLA has concentrated upon the use of the term 'service' [48]: the 2016 Guiding Principles [49] use the term no less than 140 times. Moreover, aaS applied to the broader domain of land management is realised through environmental protection interventions [50], ecosystem services [51], and organisations offering land management 'as a service' to companies as part of land rehabilitation [52].

That said, specific use or application of aaS—related to land administration, land registration, or cadastre—is far more limited, receiving some initial analysis or specific case examination in obscure or lesser-known works [53,54]. However, the domain is increasingly paying more attention to aaS. Referring to cloud, mobile, and big data technologies, [55] provides a vision for land administration systems becoming an 'as a service' platform. [56] reveal it as one potential aspect to support scaling up the use of Unmanned Aerial Vehicles (UAVs) more quickly within land administration (i.e., UAVs as-a-Service), from case work out of Rwanda, Ethiopia, and Kenya. The authors of [57] propose use of the SaaS concept as part of a Volunteer Rights-based Spatial Data Infrastructure (VRSDI) to support low-cost, faster paced land rights information capture in Iran. Generally, neither specific definitions nor overarching models of aaS are provided in these works.

Perhaps most extensively, the UNECE [11], later endorsed by FAO and FIG [58], identify 'As-a-service Land Administration' as one of 4 future scenarios for land administration in the UNECE region (Figure 4), based on mega-trend and driver analyses; the others being 'Conventional', 'Platform', and 'Distributed'. Driving the aaS scenario are issues around cybersecurity, open-data, artificial intelligence (AI), collaboration, and innovation incubators, amongst others. The aaS scenario would see more private actors engaged in land administration, although the approach would maintain the more traditional hierarchal governance arrangements (as opposed to a more decentralised or distributed setup). It would consist of defined services, process-orientation, appropriate regulation, data custodians and PPP arrangements. Examples pointed to which are already in action included land registry privatisations in Australian States and Canada, and the provision of GNSS Continuously Operating Reference Stations (CORS) in some contexts. A useful set of guiding questions supports land administrators to identify whether the aaS may have relevance within a given jurisdiction. That said, as the report covers 4 scenarios, coverage of aaS is necessarily brief.

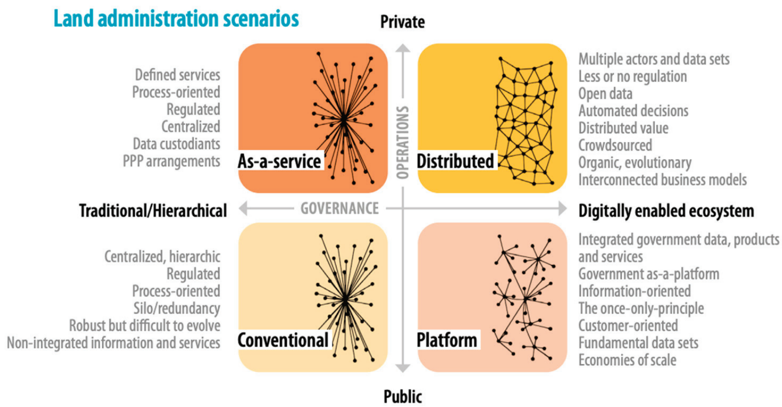

Figure 4. Land administration as-a-Service: one of 4 future scenarios for organising land administration, as defined by UNECE WPLA. (Source: [11]—from Scenario Study on Future Land Administration in the UNECE Region, by UNECE, ©2021 United Nations. Reprinted with the permission of the United Nations).

7. Modelling Land Administration As-A-Service

Taking the abovementioned (Section 6) first forays of aaS applied to land administration into account, and incorporating the results of Step 1–3 of this work (see Sections 3–5), a first attempt to develop a more detailed 'Land administration aaS' or 'LAaaS' framework is now presented.

As a fundamental starting point, for the purposes of this work, building from [46,59], land administration is understood fundamentally as an 'infrastructure' and 'public good'. Moreover, as outlined in Section 4, aaS analytical frameworks are often simplistic or overly broad, however, the baseline EA framework (i.e., Business, Application, Information, and Technology layers) was earlier identified as a potential starting point. Accordingly, it is used as the basis, with the intention to focus on adding aspects salient to the land administration domain. These additions are now explained.

First, three key actors pertinent to the domain of land administration are defined: (i) mainstream land agencies (i.e., government land administration authorities, cadastral offices, land registries, and/or mapping agencies), (ii) service providers (i.e., notaries, conveyancers, private surveyors, and IT outsourcing service providers), and (iii) customers or system users (i.e., land users, right holders, private, commercial, or public).

Second, five responsibilities and associated infrastructure components are defined: (i) business rules; (ii) applications; (iii) information; (iv) technology; and (v) transactions (or updates). The first four responsibilities build directly from EA frameworks [41]. The fifth responsibility—transactions—embodies the interaction between the land administration function and the system users of the land administration system. Transactions are usually triggered by a real-world land-related event (e.g., buying, selling, inheriting), but can also be more systemic (e.g., an annual land tax requirement and payment). Transactions are included as a layer primarily to help distinguish between the various aaS models (see below).

Subsequently, in combining the actors and responsibilities in different ways using the continuum approach, different aaS configurations are revealed. Figure 5 provides illustration. It shows five (5) generic models of aaS applied to land administration, each representing different responsibilities for the three types of actors in terms of business rules, applications, information, technology, and transactions. As can be seen, each generally provides the contextual basis upon which to design and implement the subsequent layer. These are by no means the exhaustive components in the context of understanding and implementing a full aaS offering; each option would require study and analysis of broader land administration components including those from FELA, for example: (i) Governance and Institutions; (ii) Law and Policy; (iii) Financial; (iv) Data and Processes; (v) Innovation; (vi) Standards; (vii) Partnerships; (viii) Capacity and Education; and (ix) Communications and Awareness. However, it is suggested that the model provides a robust and tangible starting point for commencing analysis of the applicability of aaS in the context of land administration, within the scope intended for this paper.

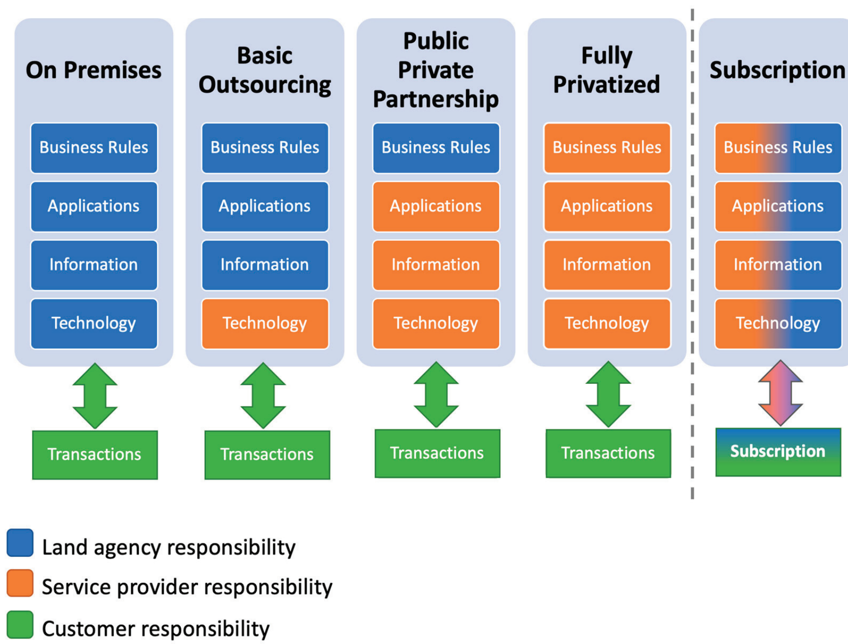

Figure 5. Options, actors, and responsibilities in aaS for land administration.

Reading left to right, the first of these, 'On Premises', is a conventional approach found in many jurisdictions, certainly before the advent of mainstreamed IT service providers. In this case, there is no role for external service providers: all responsibilities for technology and service provision are taken by a government ministry, department, or agency. This even includes surveying, mapping, and even notary/conveyance functions. Citizens instigate services by requesting transactions. This model persists in many jurisdictions, particularly emerging economies. The reformed land administration systems of Rwanda provide a prominent example. That said, the approach has been broadly in decline due to the rise of IT outsourcing, on account of the costs of IT, the opportunities delivered by cloud services and storage (i.e., commodification of IT), and the need to rapidly build data capture or IT development capacity (e.g., use of agents of the state).

The second case, 'Basic Outsourcing', depicts a conventional outsourcing arrangement, whereby IT infrastructure is provided by an external service provider. The business mandate, information, and applications remain in-house to the land agency. This might include computers, servers, internal networks, internet, cybersecurity elements, and so on. This model is sometimes found in jurisdictions where government has entered whole-of-government SLAs with technology providers (e.g., IBM and Fujitsu as examples). The model first gained prominence in the 1990s and 2000s on account of New Public Management ideologies. Many land administration systems in more developed contexts now exhibit this approach. The benefits and drawbacks of the approach are well documented in the IT literature.

The third case, 'Public Private Partnership', builds from the previous, however, more responsibilities have been transferred, usually to the private sector. There are many variations of this model, as disclosed by [60,61]. These stem from [62] and include 'Design Build', 'Operation and Maintenance Contract', 'Finance Only', 'Design, Build, Finance and Operate', 'Operate and Transfer', 'Lease, Develop and Operate', 'Build Lease', and 'Build, Own, Operate and Transfer'. Meanwhile, [63] provides another classification scheme including 'partial divestiture of public assets', 'joint venture', and 'full private sector divestiture'. For more conventional infrastructure (e.g., transport or communications networks), it is easy to appreciate that the model is focused upon the establishment and management of a tangible physical asset. For land administration, the approach becomes more abstract. A land administration system is made up of numerous components: adjudication records, survey control, boundary monuments, titles/deeds/certificates, survey plans, field notes, databases, face-to-faces offices, e-service platforms, and so on. Each of these elements can potentially become the subject of a PPP. This can include the holding of first rights of access to aggregate land transaction data. The Australian States of Victoria and New South Wales instigated such PPPs in the mid-2010s. In this regard, the model becomes more controversial: there are serious concerns regarding privacy and security of land record information, not to mention hidden and rising on-costs, especially after the initial financial gains for government are achieved. That said, there are certainly examples of where land data, particularly spatial data, is held and maintained by private entities. Indeed, there are many contexts—across most parts of the world—where private surveyors complete most of the cadastral surveying and hold (some) rights to the data. The Australian State of Queensland provides a prominent example.

The fourth case, 'Fully Privatised', represents a situation where the private sector controls land administration; government would play a minimal role, or no role at all. This is largely a fictitious case, but is analogous to customary or communally governed areas where governments may keep only rudimentary records, or not records at all. That said, in some contexts (e.g., some parts of countries in Latin America), there are cases where private sector agents are historically afforded a mandate to run a local land registry, make profits, and have little interaction with a provincial or central governments [64].

These first four models constitute the typical aaS relations of modern land administration systems. Where a specific country context sits on the aaS scale is a product of the citizen–government social contract, government policy, and financing issues within that specific jurisdiction. In terms of maintenance, these different models can be explored with regards to which setup would best enable a land administration to be kept up-to-date. Those jurisdictions that have found the appropriate model for local circumstances are also those jurisdictions that are able to maintain their land administration system. This is not to say that the aaS arrangement determines system maintenance success exclusively; it is more to say getting actor responsibilities and interactions clearly articulated and mandated is one essential ingredient, and one that perhaps many jurisdictions have not always gotten right. As a comparative example, in the Netherlands, Kadaster (the National Land Registry, Cadastre, and Mapping Agency of the Dutch), largely keeps responsibility for almost many components (Public), whilst in Canada (Ontario), and the Australian States, particularly Victoria and New South Wales, PPPs are far more evident in terms of transferral of responsibility to the private sector for technology, information, application, and even parts of the business layer[5].

Not mentioned until now is the fifth case, entitled 'Subscription'. This is a more novel aaS design, adapted from internet-based subscription e-service providers (e.g., media, communications). It is presented here as a concept, as to the best of the authors knowledge, no such cases exist in any jurisdiction. Certainly, the literature reviews underpinning this work revealed no such examples. That is, in practice this model cannot be said to be used for the purposes of maintaining land tenure information. The only disclaimer on this statement is if the broader definition of land administration is used, incorporating land valuation, land taxation, or municipal rates levying/payment, be they annual, quarterly, or at some other set epoch. Although compulsory, these could be considered as a sort of subscription service (see [65] for more on the duration or temporal nature of various property rights, restrictions, and responsibilities).

Under the model, citizens, customers, or users of the system would pay a periodic subscription fee (e.g., annual) to the lead land administration agency or land administration service provider (public or private mandate is less relevant in this case and in Figure 5, therefore the elements are illustrated with half-half shading in terms of responsibilities) to ensure their land record information was updated and secured. The subscription fee would replace the transaction-driven approach currently in place in many jurisdictions. To explain further, currently, in most systems, changes to the land administration system occur when buying, selling, subdividing, or consolidating land occurs. Transaction fees and any duties are paid accordingly. These costs can be substantial and often disincentivise citizens to lodge in the official system, particularly in emerging country contexts. In the 'subscription' regime, such one-off fees would be removed: buyers and sellers would pay a subscription fee at a regular interval and undertake transactions as needed, with no extra fees per property registered (or at some graduated scale).

Such an approach would represent a movement towards a 'subscription' based land administration service. As said, it would be somewhat analogous to current procedures around municipal or local council rates, or utility service provision, paid by landowners/holders, to receive services to lands. In these cases, a slight difference is that users pay a flat service fee (or one based on the value of the property), but are then further charged atop for any resources used (e.g., water, electricity, extra garbage removal). In the subscription model proposed, this would not necessarily be the case, i.e., provided landowners pay a set fee, they can participate within the land administration system.

What would be the advantage of such an approach? Why would a jurisdiction or country bother? One should look to the growth of subscription services in other domains for the answers, and perhaps consider the oft-misrepresented *prediction*, as presented on the social media[6] of the World Economic Forum, that "You'll own nothing. And you'll be happy". First, spreading the fee base amongst a broader proportion of the population will result in lower fees, making the land administration system more accessible in the first instance. A challenge in many contexts would be getting that broad proportion of the population into the land administration in the first place. Second, the costs associated with buying and selling are greatly reduced; the reticence or apprehension to undertake a sale, using the formal system, due to the costs involved is reduced. Third, the model results in a steadier income stream or flow the land administration agency: it is less exposed to market forces with a guaranteed set of subscribers paying yearly or periodic fees, regardless of how often they transact. Combined, these benefits help to combat the data maintenance issues from Table 1. The approach responds to long-standing issues relating to system financing, failure to register transactions, and lack of awareness, amongst others.

That said, many questions remain unexplored with regards to the aaS subscription model in land administration. Amongst others, these include: (i) How do land administrators get the base set of subscribers established? (ii) What infrastructure is needed to ensure mass payment of subscriptions? (iii) What level would the subscription fee need to be? (iv) Would the system be voluntary or compulsory—and if compulsory, does the approach merely constitute another form of land tax? (v) If private sector plays an active role in providing the subscription services, does this move a system towards title insurance, and the increased costs for transacting parties, often associated with that model? Answering these questions is outside the scope of this work. The questions emerged as part of modelling work. They require further analysis to appropriately answer. Each would require the selection and application of the appropriate research method. That said, the approach appears worthy of exploration if it is potentially able to deal with the maintenance issue. Finally, as already mentioned, each of the models presented in Figure 5 requires further articulation with respect to underlying requirements, design characteristics, and implementation approaches.

8. Conclusions and Future Prospects

In this work, the 'as-a-Service' (aaS) concept originating from the domains of IT and IS was applied to the land administration domain. Specifically, its relevance, application, and potential adaptation were assessed with reference to the well-documented challenge of failing maintenance in land administration systems. A 4-step research design, including two discrete literature reviews, a comparative analysis, and final modelling constituted the research design.

The review of the land administration maintenance literature revealed the issue was long recognised; that different understandings and terminologies have often undermined meaningful debate and solution identification; that the broader problem could be broken into 35 sub-problems categorised under the 9 FELA strategic pathways; and that land administrators must pay attention to emerging technical solutions.

The aaS review demonstrated the emergence of the concept and practice across many sectors from the 2000s onwards, thanks to the commodification of IT and the rise of low-cost internet services and storage. Benefits included reduced start-up costs, reduced ongoing costs, and perhaps most importantly for this work, easier maintenance and upgrade of IT systems.

In terms of the comparative analysis, of the 35 underlying land administration maintenance issues identified, aaS was found to enable provision of direct support to 15, indirect support to another 15, and no immediate benefit to 5. Most prominent were the ability of aaS to support issues related to financial sustainability, continuous innovation, and capacity provision.

With regards to any existing applications, the approach was found to be already in use in various country contexts and was supported by the UNECE as one of 4 scenarios for future land administration development.

Seeking to provide a more comprehensive model for aaS in land administration, the 4-layer framework from Enterprise Architecture—consisting of Business, Application, Information, Technology—was used to model and describe 5 specific aaS approaches: (i) On Premises; (ii) Basic Outsourcing; (iii) Public Private Partnership; (iv) Fully Privatised; and (v) Subscription. Several are more theoretical in nature but may see adoption in the future. Decisions on the appropriate aaS model, and aaS more generally, are entirely dependent on the specific country context. Overall, this work finds that the aaS concept has high relevance to the domain of land administration, and specifically the maintenance issue.

Areas for future research include identification and analysis of unpublished or recorded cases of aaS application within national or local land administration systems; quantitative and qualitative analysis of those cases against the various aaS models identified in this work; more detailed or refined articulations from legal, financial, and technical perspectives of each of the aaS models based on those case analyses, including costs-benefit analysis (and specifically the subscription model and the questions raised in the final paragraph of Section 7); and piloting of the models. Specific land administration transaction and services where aaS has more relevance could also be identified.

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Notes

1 Albeit already envisaged in 2002, and greatly motivated by the advent of 'big data'.

2 See: http://wef.ch/2gmBN7M (accessed 1 March 2021)

3 SaaS itself, and the other uses of 'aaS' (e.g., PaaS) tend to have more specific definitions.

4 For an example, see https://www.alibabacloud.com/knowledge/what-is-paas (accessed on 12 September 2021)

5 See: https://www.abc.net.au/news/2018-08-27/victoria-privatises-its-land-titles-and-registry-office/10169056#:~:text=The%20Victorian%20Government%20has%20privatised,up%20to%20the%20November%20election (accessed on 12 September 2021).

6 See: https://www.facebook.com/worldeconomicforum/videos/8-predictions-for-the-world-in-2030/10153920524981479/ (accessed on 12 September 2021)

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Review

Digital Twin for Active Stakeholder Participation in Land-Use Planning

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Abstract: The active participation of stakeholders is a crucial requirement for effective land-use planning (LUP). Involving stakeholders in LUP is a way of redistributing the decision-making power and ensuring social justice in land-management interventions. However, owing to the growing intricacy of sociopolitical and economic relations and the increasing number of competing claims on land, the choice of dynamic land use has become more complex, and the need to find balances between social, economic, and environmental claims and interests has become less urgent. These facts reflect a paradigm shift from top-down, noninteractive, and one-directional policymaking approaches to a more negotiable, bottom-up, deliberative, and responsible one. Geospatial industries claim that digital twin technology is a potential facilitator that improves the degree of stakeholder participation and influences land-use planning. The validity of this claim is, however, unknown. By adopting the integrative literature review, this study identifies where in LUP is stakeholder participation much needed and currently problematic, as well as how digital twin could potentially improve. The review shows that digital twins provide virtual visualisation opportunities for the identification of land-use problems and the assessment of the impacts of the proposed land uses. These offer the opportunity to improve stakeholder influence and collaboration in LUP, especially in the agenda-setting phase, where land-use issues could be identified and placed on the LUP agenda. This relies on the ability and willingness of local planning institutions to adopt digital twins, and stakeholders' perception and willingness to use digital twins for various land-use goals. Despite the assertion that digital twins could improve the influence of stakeholders in LUP, the focus and the development of digital twins have not accomplished much for those features of the technology that could improve stakeholder influence in LUP. By adopting the principles of the social construction of technology, this study proposes a "technological fix" of digital twins to focus more on improving stakeholder influence on land-use planning.

Keywords: digital twin; stakeholder participation; land-use planning; active participation

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1. Introduction

One of the current planning discourses centres on improving stakeholder participation and influence on land-use planning (LUP) measures. The inclusion of stakeholders in LUP helps to enhance planning processes, ensures responsible land-use planning, and finds balances between development needs and social life [1–5]. The underlining idea is that the LUP decision-making process should include people who will be affected by the planning intervention or those who will obstruct the process if they are not included [1,6,7]. Stakeholders can also provide "valuable knowledge and perspectives of the realities of the problems affecting their region" [8] (p. 546). Therefore, the degree of participation, the level of influence, and the decision space of stakeholders are critical to achieving responsible land-use planning [9]. However, globally, there is still a lack of active stakeholder participation in land-use planning [1,4,7,10–12]. Land-use decisions are made mainly by local authorities, excluding various stakeholders who bear the outcome of such decisions [1–3,5,13]. The role of stakeholders in various government and private planning models is mainly to choose among a set of scenarios; participate in surveys with no opportunity to come up with other suggestions, data, models, or solutions; or interact with planning officials [1,4,10,11]. This form of participation is "passive", noninteractive, and one-directional, and there are no real negotiations or deliberations involved. As a result, stakeholders have limited influence on land-use-planning decisions. Conventional geospatial technologies, such as geographic information systems (GIS), remote sensing, and volunteered geographic information (VGI), have to some extent contributed to enhancing stakeholder participation in land-use planning. However, these technologies are employed mainly in comparative analysis, land-use change monitoring, and detection, not specifically to ensure active stakeholder participation [14]. Additionally, the current visualisation tools adopted by many local authorities are still in 2D [15], are static, and lack spatial analytical functionalities [11]. Stakeholders in this case have little influence on land-use decisions as these geospatial tools are not interactive enough to provide the support needed for land-use interventions.

A digital twin is a digital representation of a physical entity [16–18]. In geospatial applications, this could include a virtual representation of land parcels, buildings, roads, utilities, proposed development, or even an entire city [19–21]. Geospatial industries claim that the digital twin (DT) technology could potentially enhance the influence of stakeholders on land-use planning [19,21–23]. Despite this claim, not many studies have attempted to establish this relationship, and there is currently no comprehensive research that has analysed or that has shown where or how this could play out. In this study, we assess how DT technology could enhance stakeholder participation and stakeholder influence on the land-use-planning process. This is accomplished by first identifying which step within the LUP process stakeholder participation is most needed and is currently problematic and second determining how and where in the LUP processes DT could improve. This research fosters and encourages active participation from and equal representation for all stakeholders in land-use planning, which are paramount in planning measures. It also shows major bottlenecks in achieving responsible land-use planning, where the needs of stakeholders are taken into consideration and all stakeholders participate in making such decisions. The study therefore seeks to provide answers to the following questions:

1. Could new technologies, and in particular digital twins, fundamentally alter the degree of stakeholder participation in and stakeholder influence on one or more stages in a land-use-planning process and, if so, how, where, and under which conditions?
2. Which qualities and potentials of the DT technology, compared with those of conventional geospatial technologies, could enhance the decision space of stakeholders in land-use planning?

The next sections of the paper are structured in the following manner: Section 2 presents a nuanced understanding of the concept of "responsible" land-use planning and how the concept is relevant to the current discourse on active stakeholder participation in land-use planning. Section 3 highlights the research process, the sources of the materials, and the method adopted in this research. Section 4 presents the results, and the interpretation and discussion of the results are presented in Section 5. The general conclusions of the research are presented in Section 6.

2. Theoretical Backgrounds

2.1. "Responsible" Land-Use Planning

"Land-use planning" is defined by Metternicht [24] as the systematic assessment of land and water potential, alternatives for land use, and economic and social conditions in order to select and adopt the best land-use options. While all the other types of planning may be spatial in terms of their geographical distribution, land-use planning directly concerns the physical space [25]. Therefore, the LUP process should involve a thorough analysis of various dimensions: the social, economic, environmental, physical, and political dimensions [26] in an iterative or continuous process [6,25]. Here, all the stakeholders are actively involved in the decision-making process [11]. Land-use planning may be termed "responsible" land-use planning, under certain conditions. The word "responsible" has been extensively used in many land-related concepts. This includes "responsible" land governance [27]; "responsible" land consolidation [28]; "responsible" land administration [29]; and "responsible" governance of tenure [30]. De Vries and Chigbu [9] (p. 70) have identified 8R indicators, namely responsiveness, respect, reliability, resilient, robustness, reflexivity, retraceability, and recognition, to describe how an intervention could be considered responsible or not. In the land-use-planning domain, various studies have also adopted the word "responsible" to describe how, where, to what extent, or under which conditions land-use planning is responsible or not. The term "responsible land-use planning" has therefore been adopted to bring new meaning to the approach, methods, and processes of land-use planning. "Responsible land-use planning" can therefore be defined as land-use planning that ensures the best use of land; that is responsive to the needs of the stakeholders; that ensures accountable decision-making; and that guarantees that all stakeholders can identify and recognise themselves in the decisions [31]. For example, Johnson [32] described how responsible land-use planning could improve stormwater management and water quality by using a geographic information system. Responsible land-use planning, therefore, goes beyond the preparation and execution of land-use planning to also include elements of responsibilities and accountabilities [31]. In the same way, it should be aligned with societal demands, should respond to the needs of the people, should reinforce sustainable development initiatives, and should improve peoples' lives [29].

2.2. Social Construction of Technology

The social construction of technology (SCOT) is a theory that supports the idea that society shapes the design and direction of technology [33,34]. Advocates of SCOT argue that the scope, form, practice, and outcome of technological development are determined by humans and certain social arenas [35]. In this sense, technology is not viewed as an autonomous tool with a fixed outcome but rather as a social construct shaped by some social preconditions and what humans tend to achieve. SCOT counters the approaches of technological determinism which views technology as an autonomous tool with a fixed outcome and no real social component or context. SCOT has four major elements: relevant social groups, interpretative flexibility, closure or stabilisation, and a wider context [34]. According to Bijker et al. [36], relevant social groups are those (organised or unorganised) groups of individuals who are connected to or concerned with an artefact. This could include producers, advocates, users, or consumers [37]. Interpretative flexibility is concerned with how people think of or interpret artefacts as well as the flexibility of how artefacts are designed [36]. Closure or stabilisation is when the problem associated with a particular artefact is solved or when the relevant social groups reach an agreement on an interpretation of an artefact [36,38]. The wider context, according to Pinch and Bijker [34], is the sociocultural and political context within which technological development takes place.

3. Materials and Methods

The application of digital twins in land-use planning is new, and there has been little discussion on it in the literature. One reason is the novelty of the digital twin technology. To examine such new topics that connect two distinct disciplines, it is important to first establish a relationship between them, which will then bring new perspectives that will lead to an initial conceptualisation and theoretical framing. Therefore, methodologically, this research adopted the integrative review, which is considered the most appropriate approach in this circumstance [39–42]. The integrative review allows the researcher to use existing literature to develop new knowledge on a topic [40]. This type of review allows dynamic topics and allows for diverse research sampling, which can include empirical, methodological, and theoretical approaches, from diverse sources, leading to a holistic understanding of a particular phenomenon [42]. An integrative review can be used to address mature, new, or emerging topics [39,41,42]. While it fills the gaps and brings new understanding and a significant reconceptualisation to ongoing topics, it also leads to a preliminary conceptualisation of new and emerging topics [41]. An integrative review is considered much more appropriate in this context than a narrative review or systematic review [43]. The integrative review, however, has been criticised for its potential for bias and its lack of rigour [43]. This research overcomes the critiques by considering findings from diverse methodologies and looking at various perspectives of the study, as suggested by Whittemore and Knafl [43]. The synthesis of this research follows the guidelines provided by Cooper [44] in undertaking review research. Cooper identifies the stages of undertaking an integrative review as follows: problem framing, data sources or literature search, the evaluation of data, data analysis, and the interpretation and presentation of the results.

The introduction section of this research highlights the research problem under investigation. This further translates into the research questions that this study aims to answer. This research connects and brings new understandings to two backgrounds: land-use planning and digital twin technology. Therefore, most of the literature in this research focuses on these two backgrounds, while other materials are from other secondary fields of study that complement this research, making it a multidisciplinary study. The literature search was systematic and commenced with an internet search of documents in various scientific databases, such as Google Scholar, Web of Science, ResearchGate, JSTOR, Springer, Taylor and Francis, and Elsevier, as well as a search of the grey literature from governmental websites, organisations, and institutions. Some of the keywords and phrases used include participation, land-use planning, active stakeholder participation, and digital twins. These keywords or phrases were used alone or in combination with another, which generated several research documents that aided in performing the validity and reliability checks.

The evaluation stage of this research included a screening process, an eligibility stage, and an inclusion stage to select the final studies used in this research. As indicated in Figure 1, the initial search of various scientific databases and websites resulted in a total of 713 research documents. Following this, duplicate documents were removed, which brought the number down to 579. After this, the titles were screened, and this resulted in the elimination of documents that were unrelated to the current study. This brought the number of research documents down to 347. The next step involved an abstract screening of the remaining documents. Studies that were not relevant to this research were excluded, yielding 93 selected documents eligible for full-text review. In this context, "relevant" means that the study focused on land-use planning and in particular addressed the issue of stakeholder participation or that it focused on the digital twin and addressed the theoretical point of the technology, its conceptualisation, its architecture, its characteristics, and its potential in land-use planning. The inductive content analysis method was used in analysing the data from the reviewed documents [45]. This included the categorisation, grouping, and abstraction of the main ideas, leading to new narratives of the connection between land-use planning and digital twins in broader themes. The data were analysed to identify where in the land-use-planning process stakeholder participation and stakeholder influence are currently critical. It was also analysed to identify those features of the digital twin technology needed to improve stakeholder influence on land-use interventions. Using logic and conceptual reasoning and the researcher's knowledge of the subject matter, we narrowed this down to specifically establish the relationship between stakeholder participation in land-use planning and the potential of the digital twin technology. The results of the findings were interpreted to confer meaning and clarity to the data. This was accomplished by discussing, comparing, and contrasting the data to find similarities in and differences between the findings and the broader literature on land-use planning [42,44]. Some data were also presented by using tables, figures, and relational models. Figure 1 summarises the literature search process.

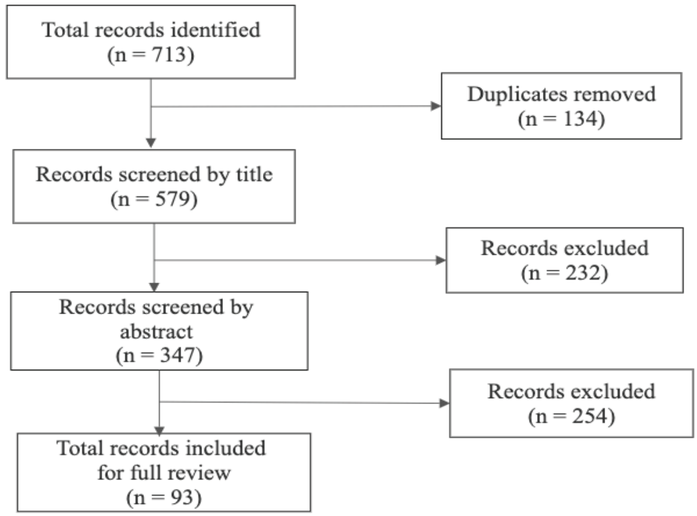

Figure 1. Literature-selection process.

4. Results

4.1. Digital Twin: Concepts, Characteristics, and Potentials

A digital twin (DT) is a digital surrogate, replica, or representation of a physical object, process, or system [17,46,47]. The underlying concept of the digital twin model is that all physical assets, people, devices, processes, places, and systems are dual: the physical nature and its virtual version [17]. The DT model can represent specific objects, such as buildings, land parcels, green areas, utilities, roads, rails, windmills, and bridges, or represent large and abstract entities, such as a city. A city-level digital twin means that the physical assets come from a group of assets in different categorisations. For example, a city digital twin would include buildings (e.g., residential, commercial, industrial), transportation systems (e.g., roads, rails), and utility lines (e.g., sewage, energy), among others. However, the inclusion or exclusion of a particular asset in a city-scale digital twin would depend on the objectives and scope of a given project. Digital twins have integrated simulation and service data that update and change as their physical counterparts change [46]. The connection between the physical asset and the digital version is established by using sensors to generate real-time data [47]. It is also facilitated through the Internet of Things (IoT) and the connectivity of advanced data analytics, which helps to predict current and future conditions for better and more-informed decisions [46]. This therefore saves time, costs, and resources because experiments can be performed on a virtual version without affecting or interfering with the physical assets [48]. Though the digital twin system is a recent initiative, the concept had already been envisioned much earlier [46]. It was first introduced as a concept for product life-cycle management, by Grieves in 2002.

The model is growing in both academia and industry [18] thanks to the advancement of IoT and artificial intelligence (AI) [49]. Although the digital twin has the capacity of being applied in almost every field of study, it has received much attention in manufacturing, healthcare, and smart city modelling [17]. For instance, the DT concept has been used for spacecraft monitoring by NASA, ocean-based production platforms by the oil industry, and smart city modelling, while the health sector has recommended it for improving patients' health [17].

The digital twin system is more than just the creation of prototypes or the display of virtual versions of physical assets. One important feature of the DT technology is its ability to exchange data with the physical twin in real time [48]. However, many articles have described the digital twin at various integration levels. That is, its integration and connection to a physical object could be performed in real time, near real time, offline, or as a virtual duplicate, depending on the context and its use case [50]. A digital twin could also be completely or partially modelled as a physical object, depending on the purpose or objective of what one intends to accomplish. Therefore, the DT concept can be said to be more of a fit-for-purpose concept rather than a one-size-fits-all concept. Table 1 depicts the various integration and fidelity levels that a digital twin concept can have. "Real time" means that there is a continual connection between the physical entity and the digital model, and any changes that occur to the physical entity automatically and simultaneously reflect on the digital component. "Near real time" means that there is a continual connection between the physical entity and the digital model, but any changes that occur on the physical entity take some time; it may take minutes, seconds, or microseconds before it reflects on the digital twin [50]. "Online" means that both the physical entity and the digital twin are connected; however, the reflections take place at a stipulated time. "Partially offline" means that the connection can be online and offline at different intervals. "Offline" or "virtual duplicate" means that there is no connection between the physical entity and the digital model; thus, the digital model is just a virtual form of or a model of the physical entity.

Table 1. Digital twin architectural perspectives and categorisations. Source: authors' construct, based on [50].

	Integration	Fidelity
Categorisation	Real time Near real time Online Offline (partial) Offline (virtual duplicate)	Complete Partial

Kritzinger et al. [51], however, classify the integration levels as follows: digital models, digital shadows, or digital twins. They classify an integration level as a digital model when there is no automatic data flow between the physical entity and the digital model; a digital shadow when there is automatic data flow but only in one direction; and a digital twin when there is an automatic data flow in two directions [51]. Digital twin technology requires the adoption of some technologies to make it possible and reach its potential. Each of these technologies has a unique role to play in the conceptualisation of digital twins. These are grouped into four main categories: the application domain, the middleware domain, the networking domain, and the object domain [18]. The application domain is for data capturing, preprocessing data, and creating high-fidelity models of physical objects and twin buildings [18]. The middleware domain has two subcategories: storage technology and data processing. This occurs basically through the integration of big-data and machine-learning technologies [48]. Big-data and machine-learning technologies also help in analysis, prediction, and optimisation. The third category is the networking domain, which performs the communication function. That is, wireless communication is needed for data communication between the digital twin architecture and the wireless transmission of the data across various IoT devices [48]. The object domain comprises the hardware platform and sensor technologies. While the hardware platform makes it possible to conduct DT analysis, the sensor technology facilitates the visualisation and collection of data for the provision of real-time information.

As indicated in Figure 2, a typical digital twin concept includes the physical entity, the digital model, and the connection between the physical entity and the digital model [52]. The entire digital twin system also has a connection to the outside world, where people could source information, visualise, and make analyses. The physical entities (twins) are connected with sensors and cameras, which generate and collect data. The digital twin receives the data from the physical twin, processes it, and sends the processed data back to the physical twin. The outside world can then visualise a real-time update on computer hardware and analyse it. The information obtained from the digital twin will then be used to improve the physical twin.

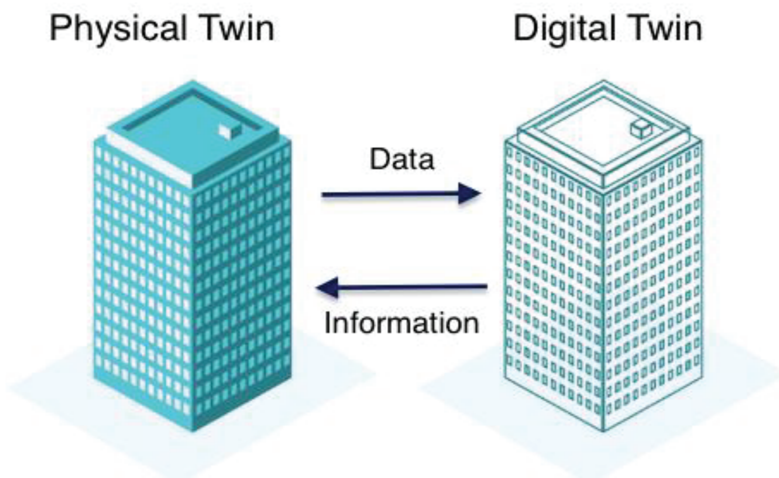

Figure 2. The connection between the physical twin and the digital twin. Source: adapted from [53].

It is important to recognise that many geospatial technologies have similar functions to those of a digital twin. These geospatial technologies can also capture, store, analyse, visualise, or manage data. For example, (open) LiDAR and drone technologies are for data acquisition; building information modelling (BIM) and geographic information systems (GIS) perform analytical and integration purposes; city geography markup language (CityGML) and immerse and virtual reality are for visualisation; and blockchain and NoSQL are for data management. Several of these technologies, including GIS, CityGML, and BIM, are also capable of producing 3D models. It is therefore important to differentiate digital twins from a conventional 3D model, BIM, and other geospatial technologies. A 3D model is a three-dimensional digital visualisation of a physical entity. BIM is a 3D model that provides compressive information about the physical entity; however, it requires manual data insertion for updates without any mutual connection to the physical entity [20]. A digital twin, on the other hand, is a 3D model of a physical entity with a mutual connection between the physical entity and the digital model and can perform in real time and in an interactive manner [20]. The characteristics indicated in Table 2 show the uniqueness of the digital twin technology.

Table 2. Characteristics of digital twins. Source: authors' construct.

Characteristics of Digital Twins	Description	Sources
Modelling and visualisation	Digital twins can capture, create, and model physical entities in 3D.	[18]
Real-time monitoring	DT can show the current status of the physical asset in real time or at a given time.	[49]
Connectivity and communication	There is a 2-way synchronising relationship between the digital model and the physical asset. It also ensures an accurate and timely flow of information through all IoT devices.	[17,48,54]
Integration capability	The digital twin system accepts the integration of other technologies.	[48]
Homogenisation	Digital twin makes the homogenisation of data possible. Digitised data from the physical asset can be computed, stored, or transmitted across various devices or agencies.	[54]
Interactive	Digital twins can respond to the user's input or action.	[55]
Analysis, prediction, and optimisation	With DT, future predictions are possible; hence, better and more-informed decisions can be made.	[18]

4.2. Land-Use Planning Phases and Stakeholder Participation

A stakeholder in land-use planning is anyone, a group or an institution with an interest, affected or anyone who will be affected by a land-use planning initiative. Stakeholders could include citizens, governmental and nongovernmental organisations, groups, companies, and institutions, among others. Stakeholders are the bearers of land-use decisions; therefore, it is prudent that they actively participate in the process. The identification of stakeholders should be one of the initial processes of land-use planning [4]. Various studies, including those by Kvam [56] and Wang and Aenis [57], recommend the adoption of stakeholder analysis as this will avoid leaving out some stakeholders and, at the same time, reveal whether to group or categorise stakeholders where necessary. The inclusion of stakeholders in the land-use planning process helps to better understand the circumstances and local dynamics that will positively shape the overall process. It also reveals the rights and responsibilities of the stakeholders and increases the chances that the project will be accepted by the stakeholders, while empowering and strengthening their trust in the land-use-planning process. In this study, we define "decision space" as the extent to which stakeholders will be able to contribute, provide feedback, and participate in the decision-making process for land uses. Like many organisational or institutional processes, the land-use-planning process includes the task of making, decisions and these decisions are crucial. Eisenfuhr [58] defined "decision-making" as "a process of making a choice from a number of alternatives to achieve the desired result". Therefore, to decide, there should be alternatives or options, there must a goal to achieve, and there must a process to choose among those options. All these elements are important to making decisions that will lead to maximisation and optimisation [59]. Therefore, decision makers should be able to figure out their alternatives, be aware of the various land-use outcomes, go through some steps or processes, choose the optimal land uses, and be able to implement them. However, local authorities alone cannot make such optimal decisions, because they might not know all the community information. The inclusion of stakeholders in the decision-making process provides the opportunity to highlight various possible alternatives related to the social, economic, and environmental dimensions. Land-use planning involves many interest groups with different perceptions and expectations of the outcome of the LUP process. Identifying what matters most and is less relevant in the land-use context is often debatable given that various stakeholders have different interests and perspectives. Planning officials and policymakers might also have different perspectives on what is relevant and what is not. For example, to the socialist, land-use planning should be able to enhance social conditions as well as the cultural dynamism of a group of people; to the economist, land-use planning should be able to generate the needed revenue or increase the economic output or land value of an area or region; to the environmentalist, land-use planning should be able to protect the biodiversity, ecosystem, flora, and fauna; and to the politician, land-use planning should be able to satisfy their political agenda. However, land-use planning should holistically assess every dimension and find a balance within these dimensions [6]. That is, land-use planning should be socially just, environmentally sustainable, economically sound, physically adaptable, and politically acceptable [6,26]. Therefore, identifying land-use problems and placing them on the agenda and in policy frameworks should be a collaborative effort from both planning officials and all other stakeholders [6].

The aim and principles of land-use planning are similar among many communities and countries; however, there are variations in the processes, methods, and approaches employed [11]. These variations are a result of differences in the institutional setup of LUP systems as well as the professional experiences gained with LUP in various environments [11]. There are also different phases of land-use planning. For instance, FAO [60] classifies land-use planning steps as follows: establish goals and terms of reference; organise the work; analyse the problems; identify opportunities for change; evaluate land suitability; appraise the alternatives; choose the best option; prepare the land-use plan; implement the plan; and monitor and revise the plan. The GIZ [6], using an iterative process, classifies land-use-planning phases as follows: definition of objective or approach;

analysis; plan formulation; approval; implementation; and monitoring. Lagopoulos [25], on the other hand, classifies LUP phases as follows: decision to intervene; survey of spatial system; policymaking; forecasting; model of spatial system; alternative spatial scenarios; evaluation and selection; and implementation. Each of these classifications demonstrates that land-use planning is not a linear process and that every phase has different types of requirements, methods, and participation processes. In the same way, the roles of stakeholders and the types of participation in the various phases of land-use planning differ. According to the GIZ classification, for example, each of the phases can be explained as follows. The problem or objective definition is the agenda-setting phase, which involves the identification and prioritisation of certain issues over others. Here, stakeholders identify pressing issues that need urgent attention and solutions. The analysis and plan-formulation stages involve the appraisal of various land-use options to select the optimal option [6]. Stakeholders contribute to these analyses by referring to not only physical conditions but also socioeconomic and cultural dimensions. The implementation and monitoring phases involve the execution of plans and the assessment of feedback on the effect of the project. Such feedback from stakeholders helps to re-evaluate land-use decisions.

4.3. Geospatial Data Twinning and Land-Use Planning

Digital twins are known for the creation of digital surrogates of physical entities [54]. In geospatial applications, this could include the creation of digital models of existing land parcels, buildings, and the various land uses or proposed developments, construction sites, and construction processes, a community, an area within a city, or even an entire city or country. Among other things, the digital twin model provides various functionalities for virtual visualisation, geospatial analysis, simulation, and prediction. That is, virtual experiments could be performed on the DT platform without interfering with the physical entity. Therefore, changes or adjustments could be made to the virtual prototypes without causing any harm to the physical entity. DT is capable of producing highly accurate and detailed 3D models for easy understanding and analysis [18]. Land-use planning, on the other side, also deals with geospatial data for analysis and decision-making [61]. A 3D geographic visualisation is a planning tool used for visual impact assessment and collaborative planning processes in both rural and urban land-use-planning initiatives [14,15,61]. Land-use-planning processes could differ depending on the process's aim, the area of concern, or the core question of the overall land-use-planning process. In the rural context, land-use planning involves the designation of various uses of land over agricultural or natural land [60]. In an urban context, land-use planning involves the assessment of land-use options, (re)designation, or change in urban land use to different uses [14]. This could include an urban regeneration process, a physical (re)organisation of the space, or urban development projects such as new market squares, bicycle lanes, roads, or tram and rail lines. Land use in the urban context is complex, and on many occasions, it involves the mixed use of land. A particular use of land also has external impacts on other uses as well as on other urban planning measures. Visually assessing such proposed use cases could highlight the impacts as well as the land-use conflicts that may arise. For example, the construction of a commercial high-rise building could be economically important; however, it could also be detrimental if it occludes other buildings from sky exposure, sunlight, or air movement (see Judge and Harrie [62]). In this scenario, it is important to assess the geographic position and the structure of the property in terms of its elevation, dimensions, extensions, and perspectives. Such planning measures involve not only the assessment of social, economic, and political dimensions of proposed developments but also physical conditions and their impact on other uses [62]. These urban management scenarios help to prevent land-use conflicts, promote sustainability, and lead to external factors such as traffic and disaster-prevention measures. Three-dimensional (3D) visualisation models of physical entities are therefore employed to improve understanding and bring about responsible decisions [63].

Land-use scenarios can be presented in two-dimensions (2D), in three-dimensions (3D), or even in a higher dimension. These dimensions have different levels of detail (LOD) and therefore different levels of contribution to analysis and decision-making. Because 3D has much more detail and it is more illustrative and comprehensible than 2D, analyses are more effective with 3D than with 2D [14,62]. This is because, terrain, building heights, and landscapes are mostly lost in 2D models [62,64]. Figure 3 shows five LODs and the level of contributions that each could offer.

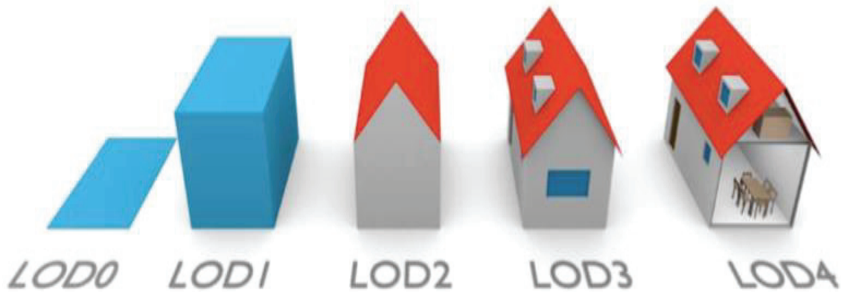

Figure 3. Levels of detail. Source: [65].

Many local authorities are gradually adapting to 3D visualisation models thanks to their added value to 2D data sets [66]. Additionally, more and more land-use dynamics require multidimensional and multispatial data sets [67]. Therefore, having a 3D model as a complement to the 2D is an effective way to conduct a comprehensive analysis. Though current geospatial technologies such as GIS, remote sensing, virtual reality (VR), augmented reality (AR), and volunteered geographic information (VGI) are used for various analytical functionalities and have 3D-modelling capabilities, the digital twin is said to be more comprehensive, be more interactive, and have various analytical functionalities that will improve the participation of stakeholders [19,68].

Digital twin technology has gained much popularity not only in academia but also among many governmental institutions, policymakers, and private organisations around the world. During the literature review, we came across some examples of where and how institutions have embraced and considered the application of digital twins in planning-related issues. As indicated in Table 3, we highlight the application areas of these examples. It can be observed that some of these digital twin adoptions are for urban development and planning interventions, some are to gather the city's spatial data or visualise urban infrastructure for planning purposes, and others are for bringing about participation and collaboration between planning authorities and stakeholders. Though the examples show that DT is considered in a way that ensures the sustainable and effective use of land, not many of these use cases aim specifically to improve the influence and collaboration of stakeholders. Additionally, few studies have demonstrated how DT could improve community participation in planning matters. For example, Shahat et al. [20] analysed a city-level digital twin; Abdeen and Sepasgozar [19] demonstrated how a smart city digital twin could improve community participation; and Dembski et al. [21] showed how communities could participate in spatial planning by using digital twin models. These studies show that DT could generally improve stakeholder participation, but not in a specific planning step.

Table 3. Examples of where and how digital twins are being considered. Source: authors' construct.

Where and How Digital Twins Are Being Considered	Source(s)
"A future-oriented and sustainable metropolis that actively and responsibly uses digitization for the benefit of urban society"	[69]
Openness, transparency, equality, and inclusion Autonomous digital twins for business and planning interventions	[70]
Virtual Singapore in 3D and a collaborative data platform Data access by various stakeholders Visualisation, enhanced planning, and decision-making Potential for solar energy production	[22]
Net-zero carbon emissions Sustainable and clean cities concept	[71]
Heritage restoration Improved operational and efficiency of infrastructure Urban resilience	[72]
Visual communication and collaboration Creation of urban planning scenarios Detailing and visualising building projects Collaboration between stakeholders	[73]
Urban-scale digital twin and integrating spatial data City data gathering Data for stakeholders Informed decisions	[23]

4.4. Current Challenges and Limitations of Digital Twins

Digital twins offer great opportunities to visualise, analyse, and predict future scenarios of physical entities. Despite its potential, several challenges limit its full utilisation. One of the main challenges, as noted by [20], is the mutual integration between the digital and physical counterparts. The communication of data from the physical entity to its virtual version is possible; however, the opposite communication of information from the virtual platform to the physical entity is currently challenging [20,51]. Additionally, a wholly mirrored city digital twin is still a challenge as the digitalisation of all physical entities is cumbersome and time-consuming, while nonphysical entities such as socioeconomic, political, and cultural patterns cannot be visualised [20]. There is growing literature on its conceptualisation; however, the technology is still in its infancy, with fewer practical applications [20]. The technology heavily relies on data to create digital models of physical entities; therefore, for large projects and city-scale initiatives, many data are required for the proper construction of digital twins [48]. These large data sets mean that large data-storage capacities are also needed. However, many studies have suggested the integration of big data as well as cloud storage initiatives into digital twins [11,20,48]. Meanwhile, the authors of [48] point out that data assembling, the extraction of duplicates, and the integration of big data into digital twins are currently challenging tasks and will be costly and time-consuming. Owing to the cost associated with the construction of DT, local planning offices with less revenue might face challenges in creating DT for their administrative staff and for residents. Currently, there are also various challenges relating to the design architecture of digital twins that are due to their complexities. As noted by Sharma et al. [48], DT requires interoperability with other components, such as real-time tools, big-data resources, and connection and visualisation tools. Assembling and linking these components can be laborious [48]. Additionally, given the design architecture of digital twins, it might be costly if the project validity period is not long enough or not able to achieve the intended purpose. One aspect of the design architecture of digital twins is how it could be linked to the outside world for use by citizens, local authorities, other governmental bodies, and all other stakeholders. Like many new technologies, DT is presumed to be difficult to understand and can be used only by a few elites in communities because of its complexities. The usage of digital twins involves internet connectivity; therefore, it is also presumed that many people in developing and transitioning countries who have limited internet access might encounter difficulties in using DT.

5. Discussion

The emergence of digital twins has brought different perspectives to how geospatial data are acquired and utilised in land-use planning. Adopting digital twins in land-use planning is, however, not straightforward, in that there are different variations and phases of LUP, where each phase has different requirements, processes, and approaches. This is shown in the examples of the LUP classifications that were carried out by FAO [60], GIZ [6], and Lagopoulos [25]. Similarly, the type of interaction, participation, and roles of stakeholders are different in each phase of LUP [6,11]. The type of interaction and roles of stakeholders in the agenda-setting, policy, or problem-framing phase is different, compared with those in land-use analysis, allocation, implementation, monitoring, or evaluation. For instance, stakeholders participate in the agenda-setting phase to decide which issues should be on the LUP agenda, while in the analysis phase, they evaluate various land-use options and choose the optimal land-use scenario. As noted by [6,11,35], the agenda-setting or problem-framing phase is equally critical, compared with other phases of LUP, as the overall objectives and issues that would be addressed in LUP are set at this stage. This phase also determines which issues go into the LUP agenda and which ones do not [35]. The level of participation and influence of stakeholders in this stage is therefore crucial [74]. However, practically, the level of interaction and participation of stakeholders in this phase is considerably low [1,7,12,14]. There is a wide array of conventional geospatial technologies that, to some extent, have contributed to improving stakeholder participation; however, these are used mostly in some specific steps in the land-use-planning process and not so much in agenda setting, problem framing, or the definition of objectives [14]. For example, GIS is used mostly in comparative analysis, land-use change monitoring, and land-use detection [75,76]; remote-sensing techniques are used mostly in change detection, risk assessment, monitoring, and urban expansion projects; light detection and ranging (LiDAR) are for data acquisition; and CityGML and BIM are for the visualisation of specific features, such as buildings [77]. These conventional geospatial tools can capture, measure, analyse, and support planning decisions; however, they are normally static, have limited spatial analytical functionalities, and are also not user-friendly [11,14], perhaps because they are not designed in a way that specifically supports participation and collaboration [67]. Notwithstanding, the static features provided by conventional geospatial technologies also play special roles in the analysis, monitoring, and evaluation phases of LUP [14,35,68,78]. As noted by Pettit et al. [14], improvements from collaboration in planning matters instead requires functional, user-friendly, dynamic, and interactive geospatial technology. Another feature that is lacking among conventional geospatial technologies is that changes in the physical entity do not cause it automatically update itself but rather require manual updates [14,21].

According to Hovik and Giannoumis [79], the adoption and use of geospatial technology depend on several factors for both the municipality and the citizens. Factors that determine a municipality's consideration to adopt a technology depend on the resources of that municipality and on the size, complexity, and dynamic nature of the municipality's social, economic, physical, and political conditions [79,80]. Additionally, some administrative cultures are more open to citizen participation than others are, and as such, they are more willing to adopt technologies to enhance the participation of their citizens in planning interventions and those citizens' influence on those interventions [79].

Improving stakeholder participation and influence in LUP processes are also contingent on whether the stakeholders are willing to use such technologies. Technology adoption theories have been used to assess individual willingness to use a particular technology. One such theory is the technology acceptance model (TAM). According to Davis et al. [81], TAM explains users' willingness to adopt and use a particular technology, which is based on two factors: perceived usefulness and perceived ease of use. Perceived usefulness is when there is a positive use–performance relationship, while perceived ease of use implies that the use of technology would require low effort [81]. The adoption and use of technology also depend on the social, environmental, and behavioural factors (individual beliefs and perceptions) at a specific point in time [79].

The advent of digital twins prompts the question whether they are merely another geospatial technology or whether they could significantly improve collaboration and the influence of stakeholders on planning matters. Wright and Davidson [55] show that several definitions and vague explanations of digital twins are leading to the loss of the actual definition and what DT entails. The variety of definitions of DT tends to mean that digital twins are just another 3D model [55]. However, according to Wright and Davidson [55], digital twins have three important parts: a digital model of an existing physical object, a physical object that keeps changing, and data evolving from the physical object that could be captured and that could dynamically update and adjust the virtual model. In that manner, digital twins are not useful if an object does not change over time, and the data associated with the change could not be captured [55]. Howard [49] also opines that such changes should be self-updating and update in real time, instead of using manual inputs and remaining outdated. They should also offer interactive and dynamic analytical features where stakeholders could perform complex analyses; select queries, filters, or data points; and visualise any changes that occur over time [22,82]. In that manner, data could be visualised and interacted with from different points, angles, and perspectives or in an immersive environment [82]. These features create the avenue for better virtual visualisation opportunities, which will improve the influence of and the collaboration between stakeholders in land-use planning, as compared to conventional geospatial tools, which help in the comparative analysis [19,52].

However, these specific features of DT have not received the needed attention among geospatial industries and in the literature. Additionally, as noted by Batty [83], another aspect that seems to be neglected in the DT concept is how people, social, and economic systems could be merged into the built environment to form a complete replica of the city. Batty [83] posits that a complete replica of a city that shows the interaction between people, the environment, social factors, and economic factors could never be achieved, because these social factors cannot be captured in the digital twin system. Additionally, various geospatial literature and government grey documents on DT have focused mainly on the physical modelling and simulation aspects of the technology and not so much on social, political, and cultural factors, which are equally relevant in land-use-planning interventions [77]. Notwithstanding, simulation and prediction are useful in specific use cases, such as noise, air, and flooding propagation analyses. Additionally, although the land-use-planning process requires that stakeholders take an active role and choose the optimal land use among several options in LUP [6,25], the current direction and development of digital twins has tended to limit these options and, at the same time, has neglected those features of the technology that are relevant in improving the influence of stakeholders on land-use planning [83,84].

6. Conclusions

This research assesses whether digital twins could fundamentally alter the degree of stakeholder participation and influence in one or more stages of a land-use-planning process; determine how, where, and under which conditions this could happen; and identify which qualities could enhance the decision space of stakeholders in land-use planning and identify the potential of the digital twin technology to be better than conventional geospatial technologies. The synthesis of the literature shows that digital twins provide virtual visualisation opportunities for the identification of land-use problems and the assessment of the impacts of the proposed land uses. These offer an opportunity to improve stakeholder influence on and their collaboration in LUP, especially in the agenda-setting, objective, or problem-framing phase of LUP, which is crucial but which currently has limited stakeholder participation and influence. This relies on local authorities' willingness and ability to adopt new technologies, such as digital twins, and stakeholders' perception and willingness to use digital twins for various land-use goals. Currently, the link between digital twins and land-use planning is attributed mainly to the physical assessment of land uses or the proposed use cases because DT is not able to capture social, economic, and political factors, which are also relevant in land-use interventions. The synthesis also demonstrates that conventional geospatial technologies have significantly and differently contributed in other phases of LUP, they have not contributed much in agenda setting or objection definition or in a way that fosters better stakeholder collaboration and influence. Digital twins, on the other hand, possess several qualities and features that are useful in specific use cases; their dynamic and interactive features are useful in improving the level of influence and decision space of stakeholders in LUP, particularly in the objective or problem-framing phase. The dynamic and interactive features of DT provide the opportunity to select queries and filters and to visualise geospatial data from different viewing points, angles, and perspectives and in certain levels of detail, thus presenting a comprehensive glimpse of potential scenarios. There is also a possibility of doing this in real time. These features provide a better understanding of realities, making stakeholders much more aware of the land-use issues within their community. This could serve as a basis for the analysis and identification of impacts and potential land-use conflicts.

Despite the publicity from geospatial industries that DT could influence the degree of stakeholder participation in LUP, the focus on DT is not so much on its dynamic and interactive features, which would improve the level of influence and the decision space of stakeholders. On the basis of the principles of the social construction of technology (SCOT), we propose a "technological fix" of digital twins, which is the process of adapting, modifying, or tweaking a technology for a particular use or purpose. SCOT sees technology as a social construct shaped by certain social arenas. The approach of SCOT means that technology possesses several functions and potentials; however, it can operate in a certain way only if it is shaped to do so. According to the principles of SCOT, a digital twin is co-constructed by certain social objectives. Therefore, to achieve active stakeholder participation in LUP, the emphasis of DT should be placed more on the influence of and collaboration between stakeholders while including the dynamic and interactive features of the technology needed in this circumstance.

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The Effect of Policy and Technological Innovations of Land Tenure on Small Landholders' Credit-Worthiness: Evidence from Ethiopia

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Abstract: Since the early 2000s, Ethiopia has been implementing one of the largest land certification and digitalization programs in Africa, underpinned by technological and policy innovations. The reform indicates a promising avenue for increasing the collateralization of land use rights for smallholder households who have been credit constrained. However, there is scant evidence to what extent these reforms have influenced access to credit. To help generate new insights and fill this gap, the study employed administrative data generated from 11 districts' digital land registers, survey data from 2296 households in 19 districts, key informant interviews, and policy and legal framework review. Descriptive and inferential statistics complemented by qualitative explanations are employed to analyze the results of the study. The results revealed that accessibility of information from the digital rural land registers increased the credit-worthiness of small landholders and reduced transaction costs and risks. The reform related to collateralization of land use rights also incentivizes financial institutions to establish new loan products for small landholders. The study concludes that while the two-stage land certification programs allow smallholders to possess documented land rights, their credit-worthiness may likely remain negligible without further technological and policy innovations. This implies two policy issues: the need to reform secured transaction laws and digitalizing registries for higher land rights trade ability.

Keywords: policy reform; digital land registers; tenure security; access to information; credit-worthiness; transaction risks; Ethiopia

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1. Introduction

In Ethiopia, land is a key natural resource and development asset for most smallholder households whose primary livelihoods depend on agriculture. Agriculture is considered the backbone of the economy, which accounts for about 34 percent of the national GDP [1]. About 74 percent of Ethiopian farmers are smallholders who contributed to more than 90 percent of both the total cultivated area and total agricultural production [2]. Agriculture is dominated by rain-fed, labor-intensive, and scarcely mechanized production systems on extremely fragmented and small land parcels [3,4]. Official data on holding size in Ethiopia shows that 38 percent of households possess less than 0.5 hectares of land, 23.65 percent hold between 0.51 and 1 hectare, 24 percent between 1.1 and 2 hectares, and the remaining 14 percent hold above 2 hectares [1]. Additionally, only two percent of smallholder landholding is irrigated, and only 3.7 of smallholders have access to agriculture machinery [3]. However, the agriculture sector continues to provide an opportunity to address Ethiopia's core development challenges, including poverty, persistent food insecurity, unemployment, climate vulnerability, and foreign exchange earnings, among others.

However, the within-sector transformation in agriculture lags because of a weak policy and enabling environment [1,3].

Researchers argue that the flow of credit from formal financial institutions (FIs) toward the agriculture sector is relatively low. Only 13 percent of the total lending provided by the formal FIs is directed to the agriculture sector, with most of this credit being channeled towards large-scale agricultural enterprises [5]. Another study found that two-thirds of smallholder farmers in Ethiopia are credit constrained, most of them (71.9 percent) due to risk factors and transaction costs (14.33 percent) [2]. These include high interest rates, collateral requirements, and a high risk of losing collateral due to the inability to repay loans [2,6]. Others also found that credit constraint is often considered one of the key barriers to the adoption of modern agricultural technologies and low agricultural productivity [5,6]. Smallholder households facing capital constraints resort to unsustainable land use practices and production systems. However, it is believed that smallholders' efficient and sustainable land use and management is essential for sustainable agricultural growth that positively contributes to the structural transformation of the country.

In this regard, documented land rights are a necessary condition for land markets and reduce the need for owners to spend resources on protecting claims [7,8]. Scholars often presumed that tenure security via land registration and titling increases access to credit by allowing landowners to use the land as collateral [9–11]. However, evidence of credit effects of land registration and certification programs have been rare and, at times, with mixed results. The ability of land tenure security to make credit access easy is a necessary precursor for the rural world in general and the agricultural sector in that it is credit access that can lead to the modernization of the agricultural economy [12]. In fact, evidence suggests that without several other factors put in place, such as an appropriate policy environment [13], the hypothesized link to credit access fails to materialize [14–16]. For instance, Deininger and Ali [7], using land registry administrative data in Lesotho, found that land and credit market activation is exclusively due to policy reform rather than the systematic urban land titling program alone.

While there is a mixed result about the effect of land registration or titling on access to credit in different parts of the world, there is scanty rigorous evidence on the effects of digital land registers on access to credit in rural Ethiopia underpinned by technological and policy innovations. Nevertheless, in 2016, Cloudburst conducted an impact evaluation of the USAID-funded two successive programs run between 2005 and 2013 and found that the Second Level Landholding Certifications (SLLC) in the program areas led to a small increase in access to credit compared to control groups [17]. Seven years later, a follow-on impact evaluation research of the same programs was undertaken by USAID, this time by commissioning another contractor called Landesa [18]. The research team found a negligible impact of SLLC on the access to credit effect, although cautious to draw this conclusion due to the small sample size. However, the study is bold enough to conclude that SLLC may increase the likelihood of households obtaining credit until peaking 5 to 6 years after receiving the SLLC and then decreases [18].

However, these studies did not account for the effect of the policy change and regulatory reforms of collateralization of land use rights enacted since 2017 and the technological innovations made since 2018 related to the National Rural Land Administration Information System (NRLAIS) and its effect on credit access to small landholders in rural Ethiopia. NRLAIS is a digital cadaster and land register that securely stores tens of millions of parcel records issued with an SLLC and holds information about the registration of sporadic subsequent land transactions, including mortgages. To fill this knowledge gap and generate new insights, this paper assessed the effect of access to information from the digital land registers, i.e., NRLAIS, on the credit-worthiness of smallholder households in rural Ethiopia. The study also assessed transaction risks of the SLLC-linked credit market anchored by new policy and regulatory reforms related to the collateralization of land use rights.

2. Background

Over the past half a century, Ethiopia has shown a faster demographic transition than the rest of Africa [19] and a rapid urbanization with an annual rate of 5.4% [20]. Although urbanization remained at 24% by 2021, agriculture will continue to dominate the economy, and competing access to land and transferability of rights remain to determine factors of the country's economy. Hence, land is among the most controversial and politically sensitive, and complex issues in Ethiopia. As such, land tenure reforms have continuously been one of the top development agendas interwoven within nation-building among various governments that ruled the country over the past centuries. The pre-1974 land tenure has been characterized by empirical regimes with a landlord to tenant land tenure relationships [21], while the socialist military regime (ruled between 1975 and 1991) is characterized by egalitarian land tenure reform [22]. The period between 1991 and 2018, led by the Ethiopian People's Revolutionary Democratic Front (EPRDF), reaffirms the state ownership of land inherited from the previous socialist military regime with limited reform regarding the transfer of usufruct rights among the hires, land lease, and rental arrangement. Since 2018, the Prosperity Party-led government has continued ruling the country without making any fundamental land policy reform, although many economic and structural reforms are being implemented. However, what remains common to all previous governments, including the current one, is that land tenure and its governance issues have been the maker and breaker of political power relations, determinants of resource allocation among societies, drivers of economic growth, and environmental sustainability.

Since the early 2000s, with the aim to improve land tenure security and incentivize land-based investment, Ethiopia has implemented one of the largest progressive two-stage land certification programs in Africa. Despite the difference in the technology employed for the adjudication of parcel boundaries and data storage, there is no big and substantive legal difference in recognizing the de facto land tenure rights between the First Level Landholding Certification (FLLC) and Second Level Landholding Certification (SLLC) programs. However, the SLLC includes value-added information related to the land parcels with geo-referenced maps to the landholding certificates and relatively precise land area measurements. Historically, the FLLC started around the end of the 1990s and ran through 2010. In contrast, the SLLC pilots have been started since 2003 and run through 2013 [23]. Since 2014, the SLLC rollout program has been launched nationwide and continued expanding in the highland parts of the country to date [24]. An existing study shows that over 25 million rural land parcels were demarcated, mapped, and issued with an SLLC as of 2022 [23]. Existing studies well documented the effects of this large-scale and cost-effective land certification program on tenure security [25], agriculture productivity [26], women empowerment [18], land rental market participation [27,28], and land disputes [29]. Although Xinyan Hu et al. [30] find that land titling affects the political trust of farmers in China, there is scant evidence to what extent this large-scale land certification program influences political trust and power relations among the rural landholders in Ethiopia.

Since 2018, there have been changes in technology innovation of digitalizing the land registers and organizational constellations in the land administration institutions. Additionally, there is a change of policy and regulatory reforms related to the collateralization of rural land use rights in Ethiopia. Firstly, along with the SLLC program, Ethiopia developed and operationalized a digital cadaster and land registration system called the National Rural Land Administration Information System (NRLAIS). Since 2018, this system has been rolled out and made operational into over 300 woredas (districts) in which over 20 million rural land parcel information is securely digitized. Abab et al. [24] found that this digital land administration information system makes updating the land records easy, transparent, less costly, and increases the availability and accessibility of land rights information to concerned bodies.

Secondly, in 2019, the Federal Government of Ethiopia enacted the Movable Property Security Rights Proclamation No. 1147/2019. Prior to this proclamation, the Amhara regional state enacted Proclamation No. 252/2017, which extended landholders' rights to include the use of land as collateral for up to 30 years. As per this proclamation, Article 16 states that in the event of default, the landholder will not be evacuated from the land, but rather the financial institution will temporarily gain the use right to recover the loan amount. The revised draft rural land administration and use proclamation at the federal government level also included a provision that enables landholders to access loans from financial institutions after securing a collateral agreement that is attested and registered by local land administration offices in NRLAIS. This policy change and regulatory reforms and technological innovations coupled with the land certification programs stimulate the financial institutions and smallholder households to behave differently than ever before. This behavior includes the financial institutions incentivized to develop a new loan product that targets small landholders and the landholders also more interested in accessing those credit products using their documented land use rights as collateral.

3. Materials and Methods

3.1. Sample Size and Data

Table 1 presents the summary of sample size, tools, and methods employed by the 2021 USAID impact evaluation study and characteristics of the digital land register's administrative data observations. The study was conducted in three regional states of Ethiopia (Amhara, Oromia, South Nation Nationalities and People (SNNP)), 19 districts, and 183 kebeles/villages. The study employed administrative data generated from the digital land registers of woredas that established the national rural land administration information system (NRLAIS). Those NRLAIS databases have been used to register all subsequent land transactions, including the registration of mortgages, and used as a matching approach with the household survey datasets. This digital register administrative data helps to implement an approach using administrative units that allows identifying the effects of the policy change and technological innovations separately from those of the two-stage systematic land registration programs.

Table 1. Summary of tools and methods used for the three rounds of panel data collection. Source Alvarado et al. [18] and Woreda Rudal Land Administration Information System (WoRLAIS), April 2023.

Data Collection Tools/Sample Size	Sampling Strategy
2021 survey: Data collection for all surveys and focus groups took place between 1 April and 16 May 2021	
Total HH surveys = 2306 HHs with no certification = 123 HHs with FLLC only = 388 HHs with parcel survey but no SLLC = 394 HHs issued with SLLC = 1391	Panel, using heads of HH and wives from 2008 and 2015 with these exceptions: • HHs from Tigray due to security • 12 kebeles from Amhara due to security • ELAP specifically targeted HHs with higher potential for agricultural investment and productivity, leading to selection bias
Digital and manual land registers data sources, February to April 2023	
Total number of woredas . . . 11 Total number of observed kebeles with registered transactions including mortgage . . . 366	from three regions: • Amhara: Achefer, Basona worena, Dangla, and Kewot • Oromia: Bora, Chiro, Tiyo, and Walmara • SNNP: Sodo Gurage, Silti, Lemo/Hadya

To help compare the results, the study also used survey data collected for the 2021 follow-on impact evaluation (IE) studies of the USAID-funded land administration programs, namely the Ethiopia Land Tenure Administration Program (ELTAP, run between 2005 and 2008) and Ethiopia Land Administration Program (ELAP, run between 2008 and 2013). The evaluation examined land certification investments to better understand the impacts and limitations of the land certification programs on rural land users. Data were previously collected in three rounds, namely, 2008 as a baseline, 2015 as the end line, and 2021 as follow-on impact evaluation studies. Additionally, qualitative data is also collected through key informant interviews with land administration officials and financial institutions.

The administrative data were generated from 11 study woredas of Amhara, Oromia, and SNNP regional states, Table 1. The digital registers administrative data after NRLAIS establishment and policy and regulatory reforms suggest that these changes triggered a distinct shift in (i) the number of registered, canceled, or amended mortgage transactions, including loan size and duration, (ii) the share of registered parcels after subsequent transactions reported by type of land transactions including the area in hectare and numbers, and (iii) share of parcels registered in the name of male-headed only, female-headed only and jointly male and female-headed households among others.

For systematic comparison, the authors selected the same woredas covered by the 2021 follow-on USAID's IE study except for woredas from the Tigray regional state. Woredas from Tigray regional states were not covered by the USAID 2021 follow-on IE study due to the war that took place in the country during the household survey data collection. In addition, 12 Kebeles in the Amhara region were excluded due to the security situation in this study area. Looking at the survey data closely, all study woredas in Amhara regional state established and made NRLAIS operational in 2019/2020. Contrarily, out of the six study woredas in the Oromia regional state, only one woreda, i.e., Bora woreda, established and made NRLAIS operational. In fact, Bora woreda is a new woreda split up from the parent Dugda woreda. According to the key informants, the other five woredas did not yet establish NRLAIS due to data quality issues with the cadastral index maps. Moreover, out of the six surveyed study woredas of SNNP, five woredas were established and made NRLAIS operational starting in 2020. However, Wendo Genet woreda has been moved to the newly established Sidama regional state and did not yet establish NRLAIS, so it was not considered in this study.

Manual data collection was also employed for those woredas without NRLAIS. While employing manual data collection in non-NRLAIS-established study woredas, it is important to note that those woredas have been registering subsequent land transactions sporadically and trying to update their semi-manual land registers. These records are considered objectively secured since they have been verified by legal and administrative procedures before the registration of those subsequent land transactions made on the legally protected land registers.

3.2. Conceptual Framework and Empirical Model

The conceptual framework presented in Figure 1 shows the causal relationship between accessing the digital land registers (NRLAIS) as a service to secure formal credits, which is anchored by innovations in policy change of collateralization of land use rights, not necessarily pledging the conventional ownership rights of the land. This relationship reflects the ability of the land use rights to be used as collateral once a smallholder household receives a land certificate. What is equally important is the innovations in the institutional constellation of the NRLAIS in terms of people, organization, and technology.

From the available literature, one can draw the conclusion that stronger land tenure and property rights founded on the right policy and regulatory frameworks and the availability and accessibility of a digital land information system can contribute to at least two investment channels related to collaterals [6,13,16] that are of interest for the current study. This includes an increase in the supply of credit and reduces the cost of contracting and monitoring enforcement of collateralization, i.e., transaction cost [31]. These transaction costs are assumed to be related to credit transaction risks. To demonstrate this relationship, the land tenure literature suggests that land registration and certification programs enhance tenure security of land and resource rights which stimulates collateralization and increase the supply of credit [32–35].

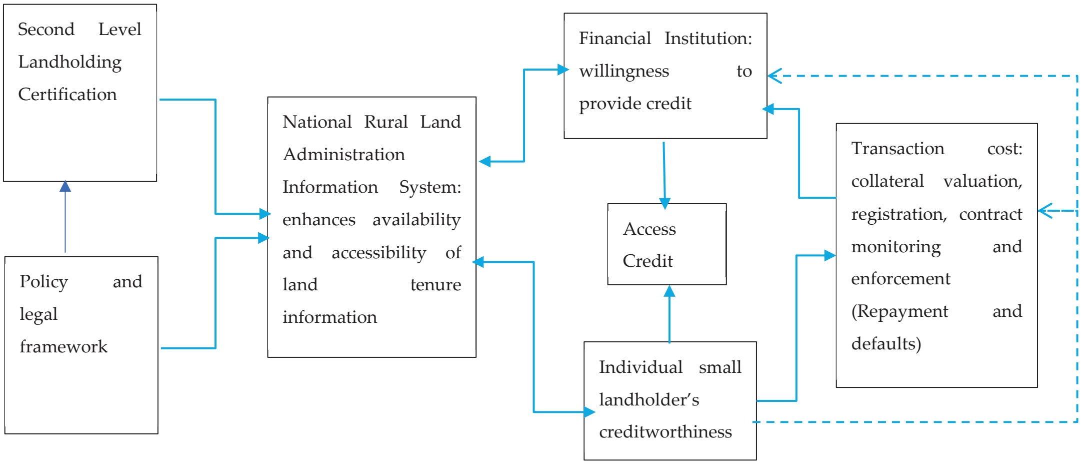

Figure 1. Conceptual framework showing the land administration information system as a service brokering to access credit by individual smallholder households from formal financial institutions. It also shows the monitoring and enforcement linkages of collateralization of contracts, including valuation, registration, repayment, and defaults. Source: Authors' construction based on the literature and own understanding, April 2023.

The effect on the credit supply is an increase in the willingness of lenders to provide credit if borrowers can use secured land as collateral [34,36]. Additionally, the creditworthiness of individual smallholders for collateral is dependent on the absence of uncertainty and asymmetric information [34,36,37]. This may be due to the availability of dependable and secure information services delivery from the land administration institutions anchored by sustainable and functional digital land information systems [16]. This incurs transaction costs but, managed properly, can reduce the inefficiencies arising from uncertainty [34,38–40]. Hence, credit impacts from land titling or registration would be expected only if such efforts are comprehensive, including enabling policy environment [13], registries remain up to date over time [41,42], and third parties, such as mortgage lenders, can access reliable land registry information at low cost on a routine basis [16].

Moreover, the existing literature suggests that transaction costs consist of the costs of measuring the valuable attributes of a right and the costs of protecting rights and enforcing contracts [38–40]. This is mostly moderated by the availability and accessibility of reliable information from a functional land register. Enforcement of contracts depends on a constellation of supporting arrangements and implementation mechanisms, such as the coordination between financial, land administration, and law enforcement institutions [34,36,40,43]. With certified land that secures land rights as collateral for credit and contract enforcement, creditors can lawfully repossess land, if necessary, arise from a default [36]. Additionally, the threat of repossession collateral acts as an incentive to the borrowers to repay the loan on time [31].

Keeping this theoretical background in mind, recent policy changes and regulatory reforms at the federal and regional state levels in Ethiopia suggest a promising avenue for increasing the collateral capacity of small landholders. Up until recently, it was uncommon practice across the country to pledge land rights as collateral for individual loans from financial institutions. As the policy changes and legal framework improves at the regional level, and the digital land administration information system coverage expands, the SLLC-linked credit is significantly expanded to non-pilot areas of the country. Hence, as part of this research objective, the conceptual framework focuses on three investment channels of the policy change and the role played by the NRLAIS on (a) signaling the credit-worthiness of individual small landholders, (b) incentivizing the willingness of financial institutions to provide credit, and (c) reducing collateralization-related transaction costs and risks.

4. Results

4.1. Descriptive Statistics

Table 2 presents sex, marital status and educational level of the survey households. Totally, 2294 household heads participated in the third round of the household survey, which was conducted between 1 April and 16 May 2021, of which 78% of the respondents were male while 22% of the respondents were female. The average age of respondents was about 55 years, with the minimum and maximum of 19 and 99 years old, respectively, showing most household heads found their active and productive ages. Out of the total 2294 respondents, 76.26% (1749) were married, of which 74.14% (1700) were males and 2.12% (49) females. To understand the literacy level of the respondents, the survey also included the highest grade of schooling completed by the respondents. The data shows that about 51% of the respondents were illiterate while about 46% of the respondents were literate, including 11.75% of them who can read and write, 19.43% and 8.24% of them completed grade 4 and grade 8, respectively. This shows that most of the respondents need some level of support to read and understand their legal land use rights, obligations, and responsibilities.

Table 2. Marital status and educational level disaggregated by sex. Source—USAID 2021.

Marital Status of HH Heads		Sex		Highest Grade of Schooling Completed by HH Heads and Marital Status							
		Male	Female	Illiterate	Read Only	Read and Write	Grade 4	Grade 8	Grade 10	Above Grade 12	Total
Unmarried/Never Married	frq	38	7	4	1	1	10	11	18	1	45
	%	1.65	0.3	0.17	0.04	0.04	0.43	0.48	0.78	0.04	1.95
Married	frq	1716	49	741	54	255	404	174	93	44	1765
	%	74.41	2.12	32.13	2.34	11.06	17.52	7.55	4.03	1.91	76.54
Divorcee	frq	21	59	67	0	5	7	0	1	0	80
	%	0.91	2.56	2.91	0	0.22	0.3	0	0.04	0	3.47
Widower/ed	frq	34	382	367	4	10	27	5	3	0	416
	%	1.47	16.61	15.92	0.17	0.43	1.17	0.22	0.15	0	34.67
Cohabiting	frq	0	1	1	0	0	0	0	0	0	1
	%	0	0.04	0.04	0	0	0	0	0	0	0.04
Total	frq	1809	497	1180	59	271	448	190	115	45	2306
	%	78.45	21.55	51.17	2.56	11.75	19.43	8.24	4.99	1.95	100

About 989 households (26% women) obtained credit between May 2019 and April 2021, which linked to 3048 parcels from different lending institutions, including microfinance (60.7%), saving and credit cooperatives (25%), individuals (13.58%), and commercial banks (0.72%), Table 3. This shows that the majority of small landholders have obtained credit from microfinance, followed by saving and credit cooperatives. The majority of heads of the survey households in the study areas practiced saving in their savings and credit cooperatives, increasing the liquidity of the cooperatives. Households with higher income, livestock, and landholding area per capita and closer to financial institutions are more likely to practice savings.

The survey results also revealed that the maximum (19 percent) and the minimum (1 percent) number of credits was obtained in March and October, respectively. Over the years (May 2019 to April 2021), 79 percent of the credit was obtained between the months of December and July, whereas the remaining 21 percent was obtained between the months of August and November, Figure 2. This shows that household heads reported that most of the credits obtained were in line with agricultural land preparation calendars.

Table 3. Number of parcels used for collateral by the respondent HH heads who obtained individual credit in the past two years (May 2019 to April 2021) by lending institutions disaggregated by sex. Source USAID 2021.

Data Source	Variables	Male	Female	Jointly Headed	Total	
					Frequency	%
2021 HH survey of USAID	Households who obtained credit (between May 2019 and April 2021)	735 (74%)	254 (26%)	NA	989	100
	Number of parcels linked to credit	2254 (74%)	794 (26%)	NA	3048	100
Number of parcels used for collateral by the respondent HH heads who obtained individual credit in the past two years by lending institutions disaggregated by sex						
	Lending institutions	Frequency	Percentage		Male	Female
	Microfinance institutions	1850	60.70		1536	314
	Saving and Credit Cooperatives	762	25.00		536	226
	Commercial Banks	22	0.72		22	0
	Individual	414	13.58		160	254
	Total	3048	100		2254	794

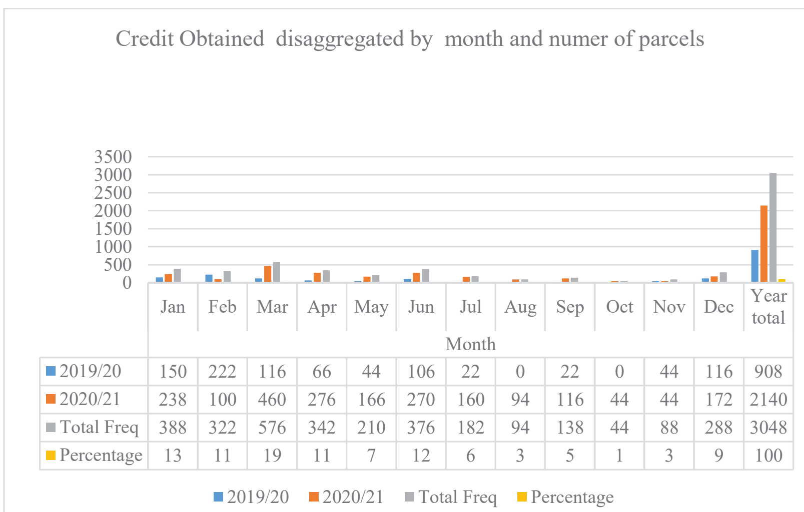

Figure 2. Number of credits obtained by household heads between May 2019 and April 2021.

Respondents were also asked about the number and size of credits obtained, length of the repayment period, use of land certificate as collateral by type, and what will happen if they are unable to repay the loans. About 39 percent of household heads obtained a credit amount ranging between 500 ET Birr and 10,000 ET Birr, whereas only 5.45 percent of household heads obtained more than 50,000 ET Birr, Table 4. The survey results also revealed that only 24 percent of household heads used their land certificate as collateral, and of those who used land certificate as collateral, 25 and 54 percent used FLLC and SLLC, respectively. This shows that creditors increasingly tended to hold SLLCs as collateral as SLLCs issuance coverage increased over time.

However, about 21 percent who reported that they have been using both FLLC and SLLC appear subject to the interpretation of contexts. This could happen when a landholder obtained one or more of the credits using FLLC in the first round before their possession of SLLC and another one after their possession of SLLC. Otherwise, this response could be generated due to the misunderstanding of the question itself since it is less likely that a landholder could have both the FLLC and SLLC to several parcels of landholdings under their possession within the same administrative registration Kebele. On the other hand, the results also revealed that 80 percent of household heads agreed to repay between 6 and 12 months, while only less than 1 percent agreed to a repayment schedule of 48 months, meaning most of the loans are short-term. Moreover, about 39 percent of the borrowers feel that they will lose their land certificate if they default on the repayment based on the terms and conditions of the credit agreement.

Table 4. Amount of credit obtained, repayment period, use and type of land certificate as collateral, and default consequence.

Amount of Credit Obtained	Freq.	Percent	Use Land Certificate as Collateral	Freq.	Percent
500–10,000	1176	38.58	Yes	734	24.08
11,000–20,000	940	30.84	No	2314	75.92
21,000–30,000	556	18.24	Total	3048	100.00
31,000–40,000	66	2.17	Type of land certificate Creditor hold		
41,000–50,000	144	4.72	First Level	182	24.80
More than 50,000	166	5.45	Second Leve	398	54.22
Total	3048	100	Both	154	20.98
Default consequence	Freq.	Percent	Length of repayment period (months)	Freq.	Percent
I will have to borrow more money from other Bank	366	12.01	Up to 6	464	15.22
I will not be able to access credit at any FIs	720	23.62	6 and 12	2440	80.05
I will lose my land certificate	1182	38.78	13 and 18	50	1.64
Nothing will happen	188	6.17	19 and 24	72	2.36
I don't know	116	3.81	48	22	0.72
Other	476	15.62	Total	3048	100
Total	3048	100.00			

4.2. Descriptive Statistics of Data from the Digital Land Registers

Table 5 presents descriptive statistics of the administrative data generated from the study woredas digital land registers in April 2023 for the period of two years (between January 2021 and December 2022). Although such data lack information on the socioeconomic characteristic of households, it includes information on the gender of registered landholders, numbers and types of transactions registered after first-time land certification, allows to compute the loan size, requested number of mortgage registration and cancellation, and estimates the SLLC-linked transaction risks.

In the current study, the total number of woredas covered by these administrative data was 11 (four woredas from Amhara and Oromia each and three woredas from SNNP regional states), covering 366 kebeles for the years 2021 and 2022. These woredas are the subset of the 19 woredas covered with the 2021 USAID impact evaluation study household surveys. According to these digital registers' administrative data, the total number of households who received SLLC-linked credits was 10,789, of which 1621 (15.02%), 1152 (10.68%), and 8016 (74.3%) were headed by men, women, and dual/jointly headed households, respectively. The mean of households who received SLLC-linked credit per kebele was 4.43, 3.14, and 21.9, headed by men, women, and dual/jointly headed in the years 2021 and 2022, respectively. This indicates that only 3 percent of households in the study kebeles obtained SLLC-linked formal individual credits over the past two years.

Likewise, these administrative datasets indicate that about 11,679 parcels with a total area of 5636.31 hectares were collateralized for the total SLLC-linked credits obtained by the households in 366 kebeles. This shows that the total number of pledged parcels for the credits obtained is more than the total number of households, meaning households were pledging one or more parcels of their landholdings to access those credits. This is particularly common practice among households in the Amhara region compared to the other two regions (Oromia and SNNP). This variation may arise due to the average parcel size in the Amhara region being less than that of the average parcel size in the Oromia and the SNNP regional states.

Table 5. Descripive statistics on households who obtained credit by pledging their land use rights represented by their second-level landholding certificates. Source: Woreda Land Administration Offices digital land register called WoRLAIS. C compiled by the authors, April 2023.

Data Source	Variables	Male-Headed	Female-Headed	Dual/Jointly Headed	Total for All Kebeles	
					Frequency	%
Digital register (WoRLAIS 2023)	Households who obtained credit (between January 2021 and December 2022)	1621 (15.02%)	1152 (10.68%)	8016 (74.3%)	10,789	100
	Number of parcels linked to credit	1754	1217	8678	11,679	100
	Total parcels area (ha)	846.57	601.96	4187.78	5636.31	100
	Total loan amount (ET Birr)	64,164,944 ($1,188,000)	45,624,607 ($845,000)	317,407,146 ($5,878,000)	427,196,697 ($7,911,000)	100
		Minimum (months)	Maximum (months)			
	Loan repayment period	12	60			
	Interest rate	8%	15%			

According to the digital land registers administrative data, the total value of credit obtained within those two years (2021 and 2022) is 427 million Ethiopian Birr (ETB) which is equivalent to about 8 million US dollars for all study kebeles. One-fourth of this loan was obtained by dual/jointly headed households, while one-tenth of the loan was channeled to women-headed households. This shows that each household obtained about 40,000 ETB on average as individual credit over the past two years. This indicates a four times loan size increment compared to the household survey loan size that was conducted for the preceding couple of years. There is a clear increase in loan size obtained by the household heads during 2021 and 2022 compared with that of 2019 and 2021 (survey result) results. This may indicate the effect of the policy change of land use collateralization which was enacted in 2019 at the Federal government level and became effective in 2020. In addition, this may be due to the availability and opportunity to access digital land information, which is securely registering mortgage transactions and guaranteeing them from third-party interests. The key informants revealed that the establishment and operations of the digital land registers at the woreda level help to monitor volumes of transactions, including mortgages at risk, and take corrective measures.

According to the key informants, most households who obtained those credits have been used to procure agricultural productivity enhancement inputs such as fertilizers, improved seeds, and pesticides as well as for animal husbandry (bull and shoats fattening, dairy farms, and poultry) that diversify their livelihoods. The key informant interviews also revealed that the credit interest rate ranges from 8 percent to 15 percent, with an average loan repayment period ranging from 12 months to 60 months, meaning most of the credits are short term like the household survey data.

4.3. Estimates of the Parameters of the Probit Regression Model

The probit regression model result indicates that among the ten hypothesized explanatory variables, seven variables were found to influence the landholder’s credit-worthiness significantly. The model result and average marginal effect size estimates are presented in Table 6. From the results, the regression model is outperformed by 7.17 percent of the baseline model. The likelihood ratio Chi-square of 162.84 with a p-value of 0.000 indicates that the current study model is statistically significant.

Table 6. Estimates of the probit regression model and average marginal effects. Source: calculated by the author based on the survey data obtained from USAID, 2022.

Credit	Coefficient (Rubst Std. Errors)	dy/dx	z	$p > \|z\|$	95% Conf. Interval
Sex	0.5674101 (0.1333088)	0.0688499	4.25	0.000	−0.0370893 0.1006104
Age	−0.0131511 (0.0018241)	−0.0015228	−7.10	0.000	−0.0020362 −0.0011554
Education	−0.0239987 (0.0156737)	−0.002912	−1.53	0.126	−0.0066413 0.0008173
Marital status	0.1669117 (0.0525938)	0.0378832	−2.19	0.001	0.0149666 0.0607998
HH type	−0.1258369 (0.0249824)	−0.0152691	−1.69	0.000	−0.0212232 −0.009315
Land area	−0.0004115 (0.0002431)	−0.0000499	−2.68	0.091	−0.0001078 7.9100006
Time taken from homestead to parcel	−0.0087632 (0.0032609)	−0.0010633	3.86	0.007	−0.0018408 −0.0002858
Parcel distance	0.0001311 (0.0000338)	0.0000159	5.07	0.000	7.830006 0.000024
FLLC	0.5447336 (0.1072497)	0.0660983	7.26	0.000	0.0405288 0.0916678
SLLC	0.4481495 (0.0618987)	0.0543787	7.26	0.000	0.0396974 0.0690601
Credit transaction risk	−0.2777714 (0.0384487)	−0.033705	−6.65	0.000	−0.043633 −0.0237769
Constant	−1.645595 (0.2118085)				

$n = 7111$, Wald Chi2(10) = 126.34, Prob > Chi2 = 0.0000; Pseudo $R^2 = 0.0717$; $p < 0.01$, $p < 0.05$; Robust standard errors are given in parentheses. Average marginal effect (dy/dx) is calculated at the mean for continuous and for a discrete change from 0 to 1 for dummy variables.

Those independent variables with positive average marginal effects include sex, parcel distance, FLLC, and SLLC, whereas age, household type, and perceived credit transaction risk have negatively affected landholders' credit-worthiness in the study areas. Education, parcel area, and time travel to the parcels were found to insignificantly affect the credit-worthiness of the landholders. The average marginal effects of each of the parameters are discussed based on their significance as follows.

Sex—the result revealed that the sex of the household head positively and significantly influenced credit-worthiness. The survey result revealed that a household headed by a male has a 7 percent increased probability of credit-worthiness compared with their counterpart household headed by a female. Meaning female-headed households were more credit constrained than their counterpart male-headed households. This may have a negative effect on the productivity and livelihood status of female-headed households in the study areas.

Age—the age of a household head is negatively and significantly affected credit-worthiness with an average marginal effect of 0.2 percent, meaning every one-year increase in the age of the household head leads to a 0.2 percent decrease in the probability of their credit-worthiness. This may indicate that households with older ages were less likely to obtain credit.

Household type—The result revealed that household type negatively and significantly affected credit-worthiness in the study areas with an average marginal effect of 1.5 percent, meaning a married household heads have a 1.5 percent decreased probability of credit-worthiness compared to their counterpart single household heads.

Land certificates—the tow-stage land certification program is one of the mechanisms sought for improving tenure security in Ethiopia. Under the current study, the survey result revealed that possessions of either FLLC or SLLC are found to positively influence credit-worthiness of household heads significantly in the study areas. The results indicated that certification increases the credit-worthiness of household heads with an average marginal effect of 7 and 5.4 percent for FLLC and SLLC, respectively. This result is consistent with the lessons of property rights theory, which predict a direct positive effect of land titling as a proxy measure of tenure security on credit-worthiness. Moreover, the result is in line with Cheng et al. [39] found households living in counties where the local governments explicitly permitted the use of land as collateral, land titling reform had a positive effect on credit in China. Piza [44] also found that land titling increases credit use, decreases reliance on credit borrowed from a relative, and increases credit borrowed from commercial banks in Brazil.

Credit transaction risk—the results of the survey indicated that perception of credit transaction risk negatively and significantly affected the credit-worthiness of household heads with an average marginal effect of 27.8 percent, meaning one-fourth of household heads were found risk averse, which hinders their credit-worthiness.

Contrarily, the survey results revealed that education, parcel area, and travel time to a parcel were found to influence on credit-worthiness of household heads negatively but insignificantly. This is a complete contradiction to the results found from the key informants' interviews of microfinance and credit and saving cooperatives in that level of literacy, and land area are part of the key parameters while assessing the credit-worthiness of credit applicants.

5. Discussion

The key objective of the current study is to assess the effect of the policy and technological innovations on the credit-worthiness of small landholders in the three highland regions (Amhara, Oromia, and SNNP) of Ethiopia. While the quantitative analysis of the household survey helps us to understand the factors influencing access to credit, the descriptive statistics of data from the land registers and qualitative policy and legal framework analysis help us to indicate the differential effect of the policy and technological innovations. The current study also looked at the willingness of financial institutions to provide SLLC-linked individual loan products measured by the volume of credit transactions and related monitoring transaction costs or risks. Based on the descriptive statistics and regression model results, this section discusses the key elements of the conceptual framework shown in Figure 1. The figure shows how the rural land administration information system as a service powered by technological innovations is brokering to access credit by individual smallholder households from formal financial institutions, moreover, how the institutional constellation helps to monitor and enforce collateral contracts, including valuation, registration, repayment, and defaults.

5.1. Policy Innovations Leads to Legislative Reforms

Access to credit for smallholder households has been much more limited in rural Ethiopia due to the absence of enabling policy and legal framework regarding financial institutions to lend money to smallholders using land as collateral, meaning smallholder households could not be able to use their usufruct rights, which is the main asset held by them, to use as collateral to access individual credit. The available option is group loans which did not always meet their needs in terms of loan size and repayment schedule. It is not surprising that even in the most advanced economies where reliable credit information and a wide range of financial products are available, borrowers have to offer collateral. Particularly, financial institutions operating in developing economies, including in Ethiopia, prefer to use immovable properties, such as land and real properties, as security interests. For instance, the land lease Proclamation 721/2011 Article 35.1 proclaimed that a leaseholder may transfer his lease-holding rights or use them as collateral or capital contribution. However, according to the Ministry of Urban and Infrastructure, only 12 percent of 6 million estimated urban land parcels and properties will be registered in the legal cadaster by the end of 2022, which is one of the collateral requirements to access credit and asked by the financial institution in the processing credit application. This increases the financial market friction with that of rural and urban land market imperfection and negatively impacts the productivity of the smallholder households as an entrepreneur in the agricultural sector.

One of the ways to increase access to credit lies in improving or reforming secured transaction laws and registries. A sound legal framework and institutional arrangement, as well as a well-functioning and secured transaction system, enables business firms and individual proprietors to use the best available assets as security to guarantee capital. In this regard, secure land tenure and property rights founded on sound policy and regulatory frameworks are vital. The sound land policy clearly contains the forms (private, communal, public and/or state, and customary) and bundle (access, withdrawal, management, exclusion, and alienation) of land tenure and property rights [45]. This, in turn, requires a clear and detailed legislative framework, including laws, regulations, and directives that specify the rights, restrictions, responsibilities, and institutional arrangements with definitive powers and accountabilities. In addition, the availability and accessibility of functional land registers with streamlined information service standards are the key enablers if the rural credit market should work for most smallholder households.

Recent policy and regulatory reforms at the regional state level in Ethiopia suggest a promising avenue for increasing the collateral capacity of smallholder households. Until 2017 in the Amhara region and 2019 at the federal government level by implication to other regions, there was no enabling policy and legal framework that promoted the collateralization of land rights to access credit. Hence, it was not a common practice across the country to pledge land rights as collateral for individual loans from financial institutions. However, the Amhara regional state amended the existing law and proclaimed new rural land administration, and used Proclamation number 252/2017. Article 16 of the same proclamation clarified and expanded landholders' rights to include the use of land use rights as collateral for up to 30 years. Under this article, in the event of default, the landholder will not be evacuated from the land, but rather the financial institution will temporarily gain the right to use the land until it recovers the loan. This can be done either by leasing/renting the subject parcel of landholding to a third party or by another means, such as agricultural profits; the landholders shall regain their landholding rights.

The current study results revealed that 60 percent and 25 percent of households obtained credit from microfinance institutions and credit and saving cooperatives, respectively, between May 2019 and April 2021. This shows that microfinance and cooperatives of credit and saving have been the main source of finance for rural smallholder households. This may indicate that those institutions will continue dominating the rural credit market over the coming years. This result is consistent with the Ethiopian Economics Association findings in that the supply of credit by formal and semi-formal financial institutions accounts for 80 percent of the total amount channeled to the agricultural sector in Ethiopia [46]. However, this may make sense where rural financial institutions can and do respond effectively to increased demand on the part of newly collateralized households [47]. Alibhal et al. [5] found in Ethiopia that only 13 percent of the total lending provided by formal financial institutions is directed to the agriculture sector, with most of this credit being channeled toward large-scale agricultural enterprises, meaning smallholder households are still credit constrained. This finding is consistent with Mukasa et al. [2], who found that two-thirds of smallholder farmers in Ethiopia are credit constrained.

However, according to the key informants, some banks which have been operating as microfinance institutions are upgrading to commercial banks and being embraced the SLLC-linked loan product for smallholder households. This includes Sinqii Bank, Tseday Bank, and Omo Bank, which were upgraded from microfinance institutions to commercial banks in the past couple of years. According to the same key informant, the UK-financed Land Investment for Transformation (LIFT) program (run between 2014 and 2021) provided technical assistance to the federal and regional governments as well as microfinance institutions to develop and pilot an agricultural credit product tailored to small landholders that catalyzes the reform. This shows that the recently enforced policy change and regulatory reform facilitated the financial institutions feeling confident and willing to provide the SLLC-linked loan product for smallholder households at scale. According to the same key informants, this policy innovation removes unnecessary restrictions on creating collateral, leaving lenders uncertain about whether a credit agreement will be enforced by law. This emerging perception is consistent with findings in other countries by Mehnaz et al. [48] in that businesses are not rationed out of the credit market because they lack assets to meet the (unnecessarily high) collateral requirements of banks and other lenders; instead, because the legal framework prevents them from using their assets to secure loans. Using registers data, Ali and Deininger [7] also found similar results in Lesotho, where land and credit market activation is exclusively due to policy reforms. Similarly, Mehnaz et al. [49] found that reforming the collateralization laws in Albania and Romania unlocked dead capital and increased access to finance, especially for small firms.

5.2. Whether Possession of Land Certificate Signals Credit-Worthiness

The land tenure literature suggests that land registration and certification programs enhance tenure security of land and resource rights which stimulates collateralization and increase the supply of credit [30,48]. Land registration becomes socially more valuable as more parcels are registered in the system because it leads to more investment and more transactions [50,51]. However, recent reviews of the evidence do not show a clear link between land certification and access to formal credit in developing economies [14,26]. Sanjak et al. [52] suggest that the expectation that land formalization will increase farmers' access to credit fails to consider other significant factors, including the farmer's income levels, the availability of credit in the market, and borrowers' business plans.

Up until the early 2000s, a large share of land in Ethiopia was undocumented and often insecure and hence could not be used as collateral. However, Ignacio [35] found that the second-level landholding certificate (SLLC)-linked individual loan product increased over time compared to the predominantly group-lending arrangements. However, the findings of the current study results indicated that only 24 percent of households who obtained any credit used their land certificate as collateral, and most of them were from the informal credit market. Despite the critical mass of smallholder households receiving land certificates in highland Ethiopia, this finding is unsurprising given that there was no supporting legal framework that allowed the use of land as collateral before 2017. This is consistent with the findings of Cloudburst in 2016 [17] in that SLLC may facilitate credit access by indicating that the loan will be used for agricultural purposes, validating livelihood and credit-worthiness, especially through alternative financing such as community-based lending and microfinancing in Ethiopia. It implies the need to have a clear legal framework and institutional infrastructures, including secured transaction systems such as collateral registries for movable and immovable assists and functional land registers. This leads us to the discussion on the role played by digital land registers in increasing the credit-worthiness of small landholders in the study areas and the willingness of financial institutions to supply more credit.

5.3. Whether Access to Digital Land Registers Signals Credit-Worthiness

Available evidence shows that based on well-defined land rights in a legal framework, low-cost access to reliable information on individual land rights reduces transaction costs and uncertainty that hinders the exchange, such as the use of land as collateral to secure credit [16]. Likewise, making information accessible in the digital land registers may facilitate the credit market. The results of the current study revealed that perception of credit transaction risk is found to influence negatively and significantly the credit-worthiness of households with an average marginal effect of 27.8 percent due to the asymmetry of information, meaning one-fourth of household heads were found risk averse. This indicates that households perceive that lack of access to information from the land registers, which is the legal information bearer of their land right, may hinder their credit-worthiness. The current rural cadastral and land registers contain spatial information about parcels (location, area, and shape) and textual information related to the landholders' particulars and the nature of rights, restrictions, and responsibilities. However, there is no information on landed properties such as houses and buildings which undermines the value and role of the land registers for land value assessment and appraisal of loan applications by lending institutions. Ethiopia's rural cadastral system may get more traction use, such as by banks and insurance companies if it is further developed in line with what Bennett et al. [53] envisioned as future cadaster and their roles in the ever-changing world.

Notwithstanding this, since 2020, access to information by the rightsholders about their legal rights from woreda digital land registers has improved when the need arises to process credit applications. Abab et al. [23] found that all mortgages or credit transactions had been registered in the digital land registers in Basona worena woreda of Ethiopia, where the system has been up and running since 2019. Results from the digital land registers of the current study show that the total number of households who received SLLC-linked credits was 10,789 with a credit value of 8 million US dollars equivalent, although only 3% of smallholder households obtained this volume of credit in the study kebeles. Figure from key informant interviews also shows that the volume of SLLC-linked loans increased and reached over 80 million US dollars were disbursed to over 50,000 rural small landholders over the past couple of years. This should not be underestimated by any measure, given that the digital registers have been fully operational only starting in 2020. This clearly indicates that the role played by access to the digital land register signaling the credit-worthiness of small landholders was found encouraging. Deininger and Goyal [16] found similar results in India in that computerization of the land registers reduces the cost associated with keeping the land register up to date, eliminates informal side payments that have traditionally been associated with property rights registration, and improves third-party access to information in the registers as well as increases credit volume.

5.4. Monitoring and Enforcement Costs and Risks of Credit Agreement

The existing literature suggests that credit transaction costs consist of the costs of measuring the valuable attributes of a right, the costs of protecting rights and enforcing contracts [32,34,38]. During the credit evaluation process, the primary focus of the lending financial institutions of smallholder households is whether an applicant has secured land rights that are registered in the land registers.

According to the key informants, procedurally, the Woreda Land Offices are the legal custodian of the digital land registers and provide each credit applicant of small landholder with a "blocking letter". The blocking letter attests that the landholder who possesses an SLLC applies for individual credit and is free from third-party interest, including those not already being used as collateral for previous credit. The small landholder applies to lend to financial institutions with supporting documents, including a copy of the SLLC and business plan demonstrating their capacity. The lending financial institution reviews their application and requests the Woreda Land Office to ensure that the SLLC is registered in the land register, only pledged once, and registers the mortgage deed on the subject parcel of landholding as collateral once the credit is approved to the applicant. The applicants should also pledge their original SLLC upon approval of the credit application to the lender's financial institution.

Based on the agreed payment schedule, the borrower is expected to repay the credit. In case of a default, the lending financial institution has the right to reclaim the land use rights of the subject parcels as a lien according to the agreed terms in the mortgage contract or until it recovers its credit amount, including the principal and interest. Recovering the defaulted credit can be collected by renting out the subject parcels to the same landholder as agricultural profits or any other potential tenant. Once the lending financial institution fully recovered the loan amount and interest, the lender writes a letter of mortgage cancellation to the pertinent Woreda Land Office. The lending financial institution also hands back the SLLC to the borrower. The Woreda Land Office updates the record in the digital land register by canceling the mortgage information registered on the subject parcel. According to the key informants, both the lending financial institutions and landholders have access to information about the legal status of the subject parcels without any service fee. This free-of-charge land information service is provided since this transaction type was recently introduced as one of the Woreda Land Office services. This may help increase the volume of registered credit transactions in the digital land register. However, if the land administration service needs to be sustainable, the Woreda Land Offices should consider reasonable service changes to the registration of mortgages in the digital land registers.

On the other hand, the establishment and operationalization of a movable collateral registry system were enacted by law. Part four of Proclamation No. 1147/2019 stipulates a collateral registry, including the establishment of the collateral registry office (Article 20) and the collateral registry (Article 21), grantor's authorization for registration of security rights (Article 22), and public access of the collateral registry (Article 24), among others. Additionally, in 2020, the National Bank of Ethiopia (NBE) adopted two directives that helped to materialize the implementation of this proclamation. The first one is directive number 186/2020 which stipulates the codification, valuation, and registration of movable properties, including land use rights. Directive number 186/2020 Article 7 sub-Articles 1 to 5 stipulate the land use rights codification, valuation, and registration. The second directive number MCR/01/2020, focuses on the operationalization of a movable collateral registry, which is an electronic registry system established for receiving, storing, and making information available and accessible to the public about the security of rights and non-consensual rights in movable properties (Article 2.2). However, there is no clear plan for the establishment and operationalization of a secured electronic movable collateral registry system and how this new system interface with the existing systems such as NRLAIS.

6. Conclusions

This study assessed the policy and technological innovation of land tenure on the credit-worthiness of the smallholder households in three highland regional states (Amhara, Oromia, and SNNP) in Ethiopia, who have often been credit constrained. The study explored the differential effects of access to information from the digital land registry on improving the credit-worthiness of the smallholder households in the study areas from that of the two-stage land certification program in the country. Additionally, the study contributed to an important assumption yet controversial argument in much literature in the field regarding land titling alone would lead to more credit access. The study tests the extent to which this is valid and identifies the needed requirements which make this argument valid or not. This was possible by employing quantitative data analysis generated from the digital land register or NRLAIS and the 2021 USAID impact evaluation household survey data complemented with key informant interviews and policy and legal document reviews. This approach also allows for identifying the effect of policy and regulatory reforms on the credit-worthiness of small landholders. The approach yielded to fill the knowledge gap on how reforming secure transaction laws and registers increases the credit-worthiness of smallholder households, reduces credit transaction costs and risks, and increases the willingness of financial institutions to provide credits to smallholder households.

These reforms represent a paradigm shift from the previous approach and allow rural smallholder households to access the capital required to move from subsistence farming to more productive, sustainable land use practices, commercial farming, and the development of the non-farm economy. The study concludes that while the two-stage land certification programs allow smallholders to possess documented land rights and increase the value of land, their credit-worthiness may likely remain negligible without such further technological and policy innovations. This implies two policy implications, including land tenure improvement interventions such as land registration and certification, need to be supported with reforming secure transaction law and digitalization of land registers for higher level land rights trade ability such as functional credit and land market. Based on the findings, the study recommends that policymakers and practitioners in the land sector should strengthen their efforts to raise the awareness and financial literacy of smallholder households as well as streamline procedures and service fee structures of mortgage registration.

While the enactment of Proclamation No. 1147/2019 and its implementing directives are welcoming policy actions, the current study did not assess the implementation effectiveness of this policy from the credit supply side, i.e., financial institution and enforcement mechanism. Future research should look at this dimension, particularly the establishment and operationalization of the movable collateral registry system and its interoperability with the digital land registers and their effect on the national economy.

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Article

Standardized Description of Degraded Land Reclamation Actions and Mapping of Actors' Roles: A Key Step for Action in Combatting Desertification (Niger)

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Abstract: Land degradation is a major issue in the Sahel region. Numerous investments have been made in implementing sustainable land management (SLM) actions to reverse land degradation. Our work aims to (i) describe the variety of degraded land reclamation actions (DLRAs) and (ii) map the stakeholders acting in Niger. A time series (2008–2021) of georeferenced public data was collected and organized using a harmonized nomenclature. The results show that about 279,074 ha could be analysed in our study. Dug structures are the most widespread technique, while treated land is mostly devoted to single agricultural or pastoral uses. DLRAs are unevenly distributed in the Niger. More than 100 stakeholders were part of the effort to restore degraded land in the country—some playing a specific role, while others, such as the Government of the Niger, were responsible for mobilizing funds for implementing sustainable land management programs, while also carrying out certain programmes of their own. Our study points out the added value of creating a geolocalized dataset and, in future, a spatialized database management system to (i) deploy targeted sustainable land management actions complementing past and ongoing actions and (ii) create synergy between all the stakeholders.

Keywords: biophysical actions; combat land degradation; stakeholder network; spatiotemporal database; traceability; monitoring and evaluation

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1. Introduction

The well-being and livelihoods of rural populations are strongly dependent on the health and productivity of land [1,2]. Natural resources overuse and increasing demand are causing rapid land degradation worldwide [3]. Degradation is characterized by a negative trend in the state of the land [4]. It involves the total or partial loss of vegetation cover, soil fertility, productivity, and/or biodiversity, leading to a decline in ecosystem services and socio-ecosystem resilience [5]. In fact, 52% of soils are moderately or severely degraded on a global scale [3]. In sub-Saharan Africa, the situation is worse. It is estimated that 75% of arable land is degraded or highly degraded [6].

In the Sahel, land degradation is the result of human activities that overexploit non-renewable natural resources in a constrained biophysical environment [7–9], exacerbated by climate change and biodiversity loss [10]. In most Sahelian countries, land degradation is not compensated by actions that aim to restore or rehabilitate degraded land. The net result is negative [11]. Thus, the deterioration of the physical-chemical and hydrological properties of soils leads to an increase in water and wind erosion [12], and a decrease in the productive capacity of semi-arid ecosystems. Economic losses equivalent to 10–17% of global GDP are attributed to land degradation [13]. The well-being of 3.2 billion people is impacted, and one million animal and plant species could disappear by 2050 [14].

Reducing or slowing down land degradation, and rehabilitating or restoring (where possible) degraded land is the challenge of Sustainable Development Goal (SDG) 15.3 of the United Nations. Moreover, beyond this single target, this issue also concerns food security (SDG 2), poverty reduction (SDG 1), water quality (SDG 6), and mitigation of and adaptation to climate change [15].

Several international initiatives promoting actions to treat degraded land have been launched. These include the Bonn Challenge launched in 2011 with the goal of treating 150 million ha by 2020 and 350 million ha by 2030 [16]. The African Forest Landscape Restoration Initiative launched in 2015 aims to treat 100 million ha of degraded land by 2030 [16]. The "4‰ Initiative: Soils for Food Security and Climate" launched in 2015 proposes to annually increase the organic carbon stock in cultivated soils by 4‰ at the global level to offset the annual increase in anthropogenic CO_2 emissions. In the Sahel, the Great Green Wall (GGW) initiative launched in 2007 aims to treat 100 million ha of degraded land by 2030.

In this context, adopting sustainable land management practices (SLM) is a solution to promote better management of natural resources and establish the foundations of sustainable economic and social development [17]. SLM practices and approaches help treat degraded land [18,19], but also prevent or slow down their degradation.

As in other Sahelian countries, in the Niger the strong anthropization of rural areas has led to the degradation of over 60 percent of arable land [20]. This situation is characterized by the disappearance of vegetation cover and soil crusting [21–23]. Many SLM initiatives have been implemented since 1984, with combating desertification declared a "national priority." As a matter of fact, projects and programmes led by a wide diversity of stakeholders have endeavoured to treat land degradation by promoting a wide range of techniques and technologies. However, there has been a lack of stocktaking at the national level in the Niger around the implementation of degradation land reclamation actions—both in terms of location and the roles played by the various stakeholders. Our work, part of a broader project entitled "Large scale assessment of land degradation to guide future investments in sustainable land management in the Great Green Wall countries (Global Environment Facility grant 9825), aims to fill those gaps. In addition, it maps the links between the roles of the different actors (donors, fund mobilizers, operators, and implementers). To this end, we have developed a spatially referenced data table that lists and maps temporally sequenced (2008–2021) geolocated data. These data have been collected from publicly accessible sources.

2. Methodological Approaches

2.1. Data Collection on SLM Actions and Construction of a Spatially Referenced Data Table, Viewable in GIS, for the Traceability of Degraded Land Reclamation Actions (DLRA)

Seven main steps were followed (Figure 1).

Step 1: Information mobilization

The aim was to collect and centralize all types of public data dealing with SLM actions carried out in Niger between February and June 2022, from the oldest to the most recent, in various formats and media, available online or distributed among the structures holding the data (public, parapublic, or private). To identify these different structures, a pre-established survey form was distributed to an initial list of 20 active structures, made up of NGOs, projects, and development programmes present in Niger. Interviews were also conducted with civil society and bilateral cooperation actors in order to make a brief diagnosis of the databases of SLM actions in Niger. The consultation of technical documents (such as study reports), scientific articles, websites, and institutional databases dealing with degradation, treatment, or SLM, helped complete the information thus collected.

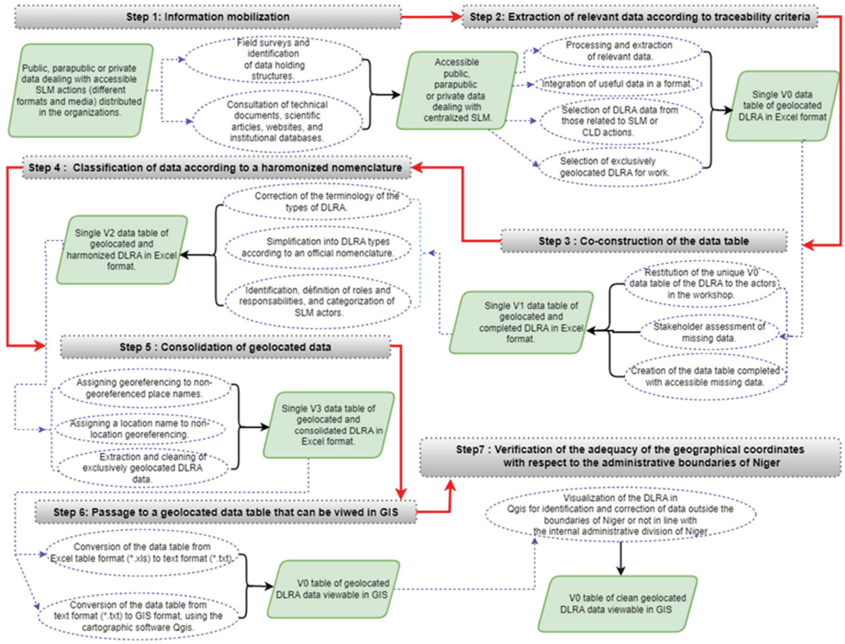

Figure 1. Steps to build a GIS of DLRA data according to traceability criteria. Note: V0 = Version 0; V1 = Version 1; V2 = Version 2; V3 = Version 3.

Step 2: Extraction of relevant data according to traceability criteria

The information collected was sorted, and the useful data were extracted and integrated into a single data table in Excel format. From the range of SLM actions or those designed to combat land degradation (ADA), the DLRA implemented in the field were selected (Figure 2).

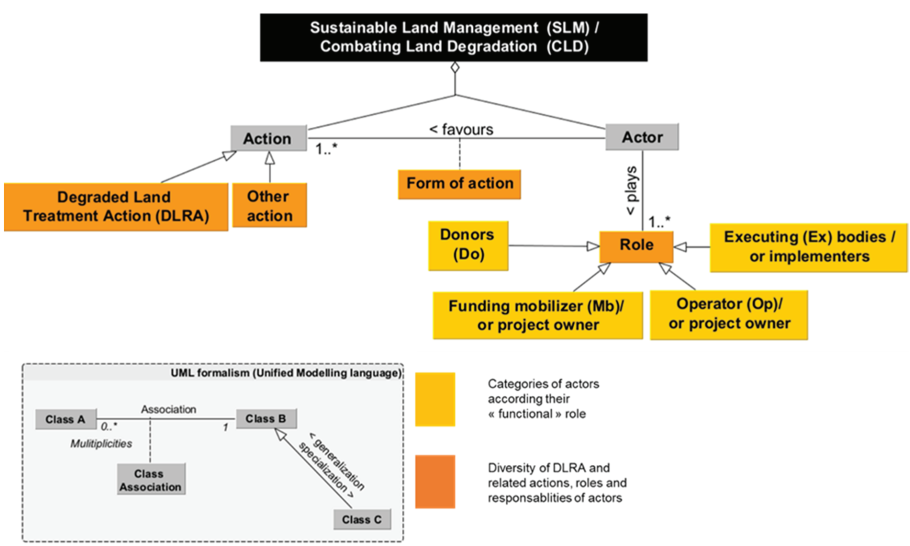

Figure 2. Schematic of the method for classifying DLRA data according to a harmonized nomenclature. Note: * indicates that an actor can play one or several roles in SLM in Niger.

Only geolocated DLRAs were selected for our work. Geolocation is a key traceability criterion, as it allows anyone to return to the places where the DLRAs were implemented and to avoid having to inventory the same action several times. The other traceability criteria are the type of DLRA; the area treated, the spatial entity (region, department, commune, village), the year, the purpose; and the donors, the actors who mobilize these donors, the operators, and the implementing entities on the ground.

Step 3: Co-construction of the data table

The result of this work of collecting and organizing data on DLRAs was presented to some thirty actors representing the various structures in order to gather their analysis on the construction of this data table and to enrich it with projects that had been overlooked until then.

Step 4: Classification of data according to a harmonized nomenclature

Each DLRA was described according to the official national technical sheets for SLM actions in Niger [24,25]. When the DLRA at a site is a combination of several actions, the name of the action with the largest treated area is used.

To define the roles and responsibilities of the different actors, it was necessary to return to the project documents. Four categories of actors were identified along the chain (Figure 2): (1) donors (Do); (2) fund mobilizers (Fm)—who identify and mobilize funds; (3) operators (Op)—who put DLRAs in action; and (4) and implementers (Im)—who implement DRFLAs in the field.

Step 5: Consolidation of geolocated data

The collection of data from multiple sources generated geolocation errors and inconsistencies. Systematic georeferencing and localization work was then carried out: (1) by assigning a georeference to the names of non-georeferenced localities, and conversely, (2) by assigning the name of a locality to the georeference without locality. All these operations were carried out using tools such as Google Earth and Geonames (https://www.geonames.org/, accessed on 12 December 2022). Only those DLRAs that were consolidated in this way from a geolocation point of view were retained. The subsequent cleaning of the data table consisted of (1) deleting the data collected that did not relate to the DLRA; (2) deleting the DLRAs that did not contain all the descriptive data that would allow them to be traced (cf. step 2); (3) correcting the input errors detected and standardizing the formats of the geographical coordinates; and (4) deleting the duplicates.

Step 6: Passage to a geolocated data table that can be viewed in GIS

Once the geolocated dataset and other traceability criteria had been filled in, their Excel table format (*.xls) was converted into text format (*.txt) and then into GIS format, using the mapping software Qgis.

Step 7: Verification of the adequacy of the geographical coordinates with respect to the administrative boundaries of Niger

Viewing the DLRAs in Qgis revealed that some of them are outside Niger or do not fit into the internal administrative division (region, department, commune). Using the attribute table and tools such as Google Earth and Geonames, they were then brought back to the corresponding administrative boundaries.

2.2. Data Analysis

The analytical work is based on a single parameter: the total area of land treated contained in our date base (e.g., 279,074 ha). The analyses (in Excel 2013) were carried out on the harmonized and consolidated DLRA data. The e!Sankey software (version 5.2.1) was used to visualize (i) for each of the roles (e.g., Do, Fm, Op, and Im), the respective contribution to each of the categories of actors (see Tables S1–S5); and (ii) their interactions (e.g., the funds of which donors are mobilized by which fund mobilizers, and then used to support the actions of which operators, who in turn entrust which category of implementers to carry out the actions required to treat a total of 279,074 ha). The size of the nodes (Do, Fm, Op, and Im) and the links between each category of actors depend on their contribution to the role and the interactions of the actors. The results are expressed as a percentage of the total area treated (Table S6).

3. Results

3.1. Data Table: Keys to Identifying and Harmonizing the Nomenclature of DLRA in Niger

Given the diversity of DLRAs in terms of an official nomenclature (see Step 4), they have been grouped together according to two levels of structuring (Figure 3: in green, first level; in grey, second level). This grouping is the result of a consensus between Nigerien LCD experts at the end of a three-day workshop.

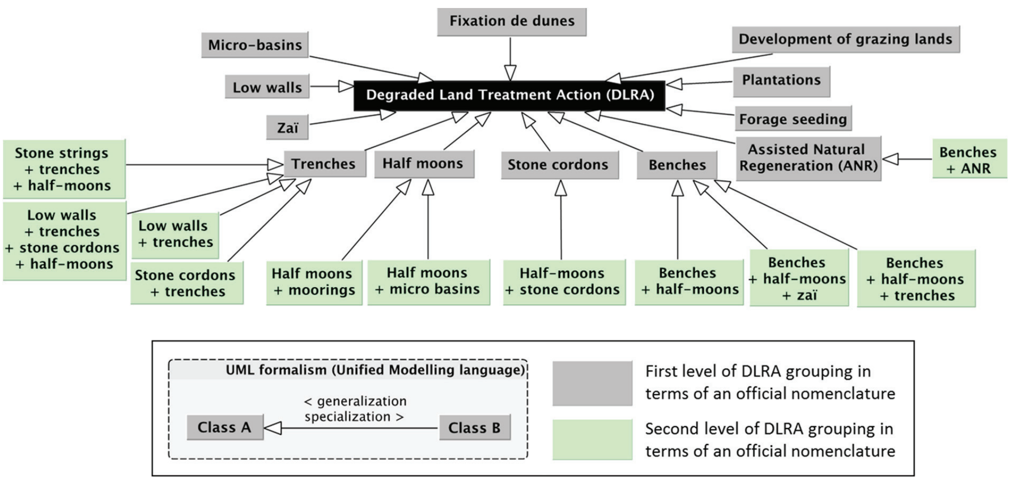

Figure 3. Scheme for grouping DLRAs in Niger according to a harmonized nomenclature.

Trenches are works dug along a line, within which several stone cordons may be placed, and between two lines of trenches several half-moons are dug. In principle, where trenches exist, they take precedence over other excavated works. The same applies to a low wall that is dug along a slope or a gully. In a trenched area, one or more low walls can be built upstream to slow down the runoff.

The DLRAs grouped under the nomenclature of "half-moons" are the combinations of half-moons associated with low walls and half-moons associated with micro-pools. The half-moons therefore take precedence over the low walls and micro-pools constructed to treat koris. A kori is a low-lying area with the appearance of a dry riverbed in the dry season and experiencing strong runoff after the rain. The low walls and micro-pools are most often downstream of other dug structures, such as half-moons, that occupy a higher surface.

The DLRAs grouped under the nomenclature of "stone cordons" are in fact half-moons associated with stone cordons, based on the principle that between two lines of stone cordons several half-moons can be dug.

The DLRAs grouped under the nomenclature of "benches" are those associated with half-moons or zaïs, or those associated with trenches. In fact, benches are long excavations laid out on the contour line. They consist of a bead at the downstream end and a ditch at the upstream end with two wings, where the space between the wings and along the edges can be used to dig half-moons, zaïs, or trenches.

In total, 17 "elementary" DLRA types were differentiated, but as the typology in Figure 3 shows, they are most often combined on the same plot:

- Eleven of these are dug structures (half-moons, benches, stone barriers, trenches, low walls, zaï, and micro-basins) for soil and water conservation (SWC), soil defence, and restoration (SDR), and almost always combined; these are mechanical actions.
- One is a biological action of SWC and SDR, namely dune fixation.
- Four are biological agricultural actions (assisted natural regeneration (ANR) practices and tree planting in agroforestry/forestry and pastoral rangeland management and forage seeding in pastoralism).
- A combination of mechanical (bench) and biological (ANR) actions.

3.2. Dugouts at the Heart of Degraded Land Treatment in Niger

The DLRA data table shows that a total of 279,074 ha of degraded land treated in Niger has been georeferenced over the period 2008 to 2021. In general, dug-out structures remain at 80% (i.e., 223,822 ha of the total area of treated land) at the heart of the treatment of degraded land in Niger. However, the georeferenced treated areas vary significantly between the different types of DLRA (Figure 4). Thus, with 170,424 ha (61%), half-moons occupy the largest area of total land treated. They are followed by dune fixation and benches with, respectively, 39,230 ha (14%) and 38,072 ha (13%). The other DLRA represent only 12% of the total area treated, with 7806 ha (3%) for stone cordons, 7394 ha for forage seeding (3%), 4534 ha (2%) for trenches, 3122 ha (1%) for plantations, 3090 ha (1%) for ANR, 2415 ha (0.9%) for grazing lands, 1398 ha (0.6%) for zaï, 1173 ha (0.4%) for low walls, and 414 ha (0.1%) for micro-basins.

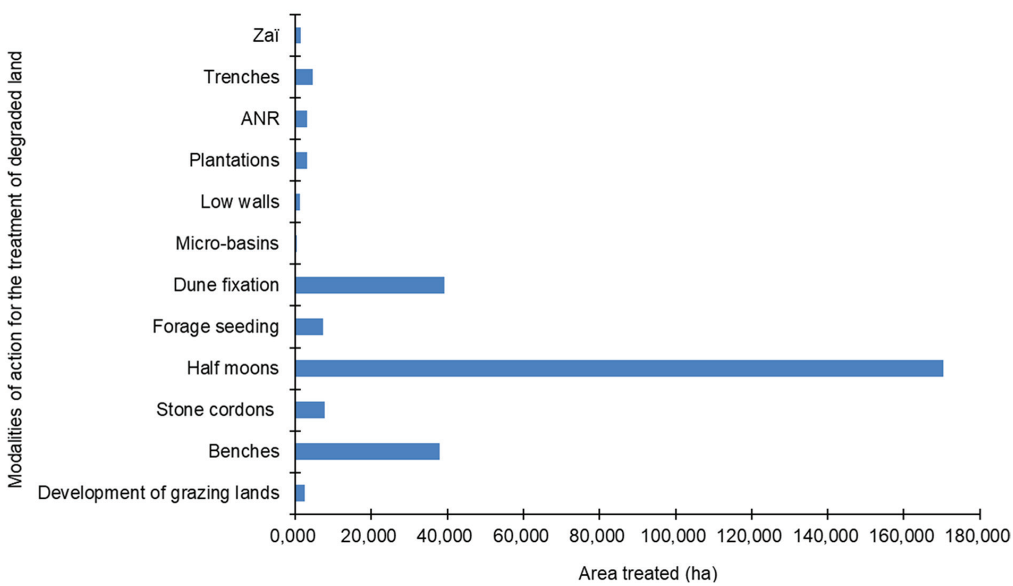

Figure 4. Distribution of the area of degraded land treated according to the type of DLRA carried out in Niger.

The DLRA are implemented on land with different uses (Figure 5). The largest proportion of land treated (168,992 ha, or 60%) is agricultural or pastoral. Pastoral land (e.g., silvopastoral, agropastoral, and agrosylvopastoral) and forestry land (silvicultural and agrosilvicultural) represent 36% and 4% of the land treated, respectively.

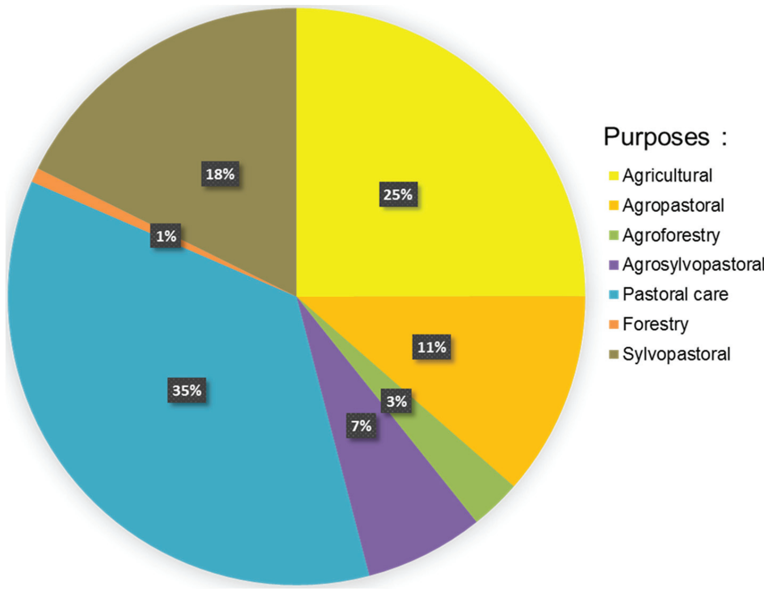

Figure 5. Breakdown of the proportion of degraded land treated by type of DLRA use provided in Niger.

3.3. DLRAs Are Unevenly Distributed in Niger

3.3.1. Analysis by Administrative Region of the Spatial Distribution of DLRAs

From 2008 to 2021, the proportions of land treated in each year relative to the total over the period vary from year to year (Figure 6). In 2012, the most land was treated by DLRA. Indeed, almost 20% of all land treated was treated in 2012, that is 50,844 ha. In 2013, 2014, 2015, 2016, 2017, and 2021, about 10% of the total 279,074 ha recorded in our database was treated per year. The years 2008, 2009, 2010, 2011, 2018, 2019, and 2021 saw low investments in SLM. The political will of the State of Niger is illustrated through the launch of the 3N programme "Nigériens Nourrissent les Nigériens", and the implementation of various programmes (e.g., COMPACT of the Millennium Challenge Account, the Programme for the Development of Family Farming in the Regions of Maradi, Tahoua and Zinder (ProDAF), and the Support Project for Rural Activities and Financing of Agricultural Commodity Chains in the regions of Agadez and Tahoua). On the other hand, the years of low investment can be explained both by projects that have come to an end, others that have not started, and for 2020 by the health situation slowing down the execution of the projects.

Expressed as a proportion of the total area of land treated (i.e., 279,074 ha), the contribution of the actions differs according to the administrative regions of Niger (Figure 7). The Tahoua region represents, with all types of actions taken together, the highest proportion of the total land treated (26%). The existence, since 2008, of data documenting the actions undertaken in this region is one of the reasons for this result. In contrast, a lower share of land treatment actions in the other regions can be explained by a lack of data. Conversely, only 1% of the actions to treat degraded land are carried out in the Niamey region. Without ignoring the issue of archiving actions, this result can also be explained by the very urban nature of this region and therefore the weakness of efforts made on the outskirts of the city. For the other regions, the proportions of land treated are almost equivalent, in ascending order, between the regions of Zinder (14%) and Diffa (13%), Maradi (16%) and Tillabéri (16%), and finally Dosso (7%) and Agadez (7%).

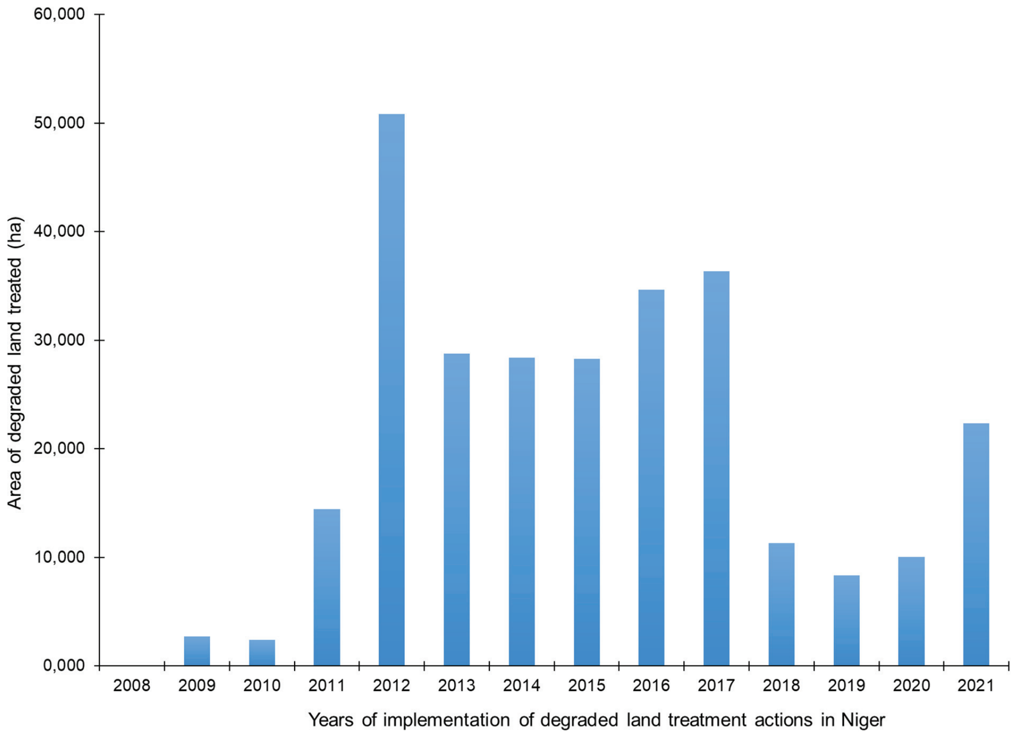

Figure 6. Variation in area of DLRAs by year in Niger.

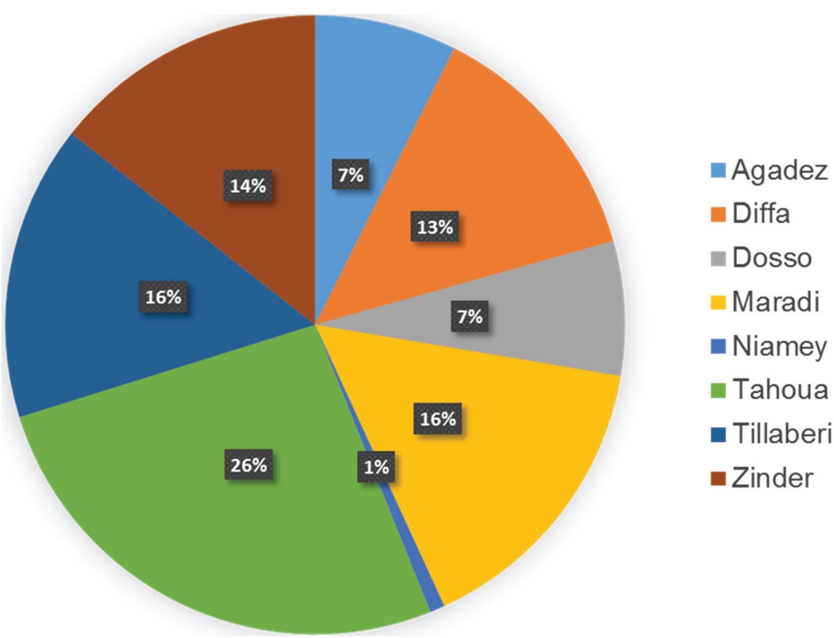

Figure 7. Distribution of the proportion of degraded land treated according to administrative regions in Niger.

3.3.2. Type Analysis of the Spatial Distribution of DLRA

The visual analysis is made possible by the use of symbols in Figure 8 that distinguish between types of DLRA. Geolocated DLRAs are found mainly in the southern half of Niger, an agricultural area par excellence. Half-moons and benches predominate in all regions of Niger, except in Diffa where benches are absent. The sandy and sometimes clayey soils in the lowlands of this region are not conducive to the deployment of benches.

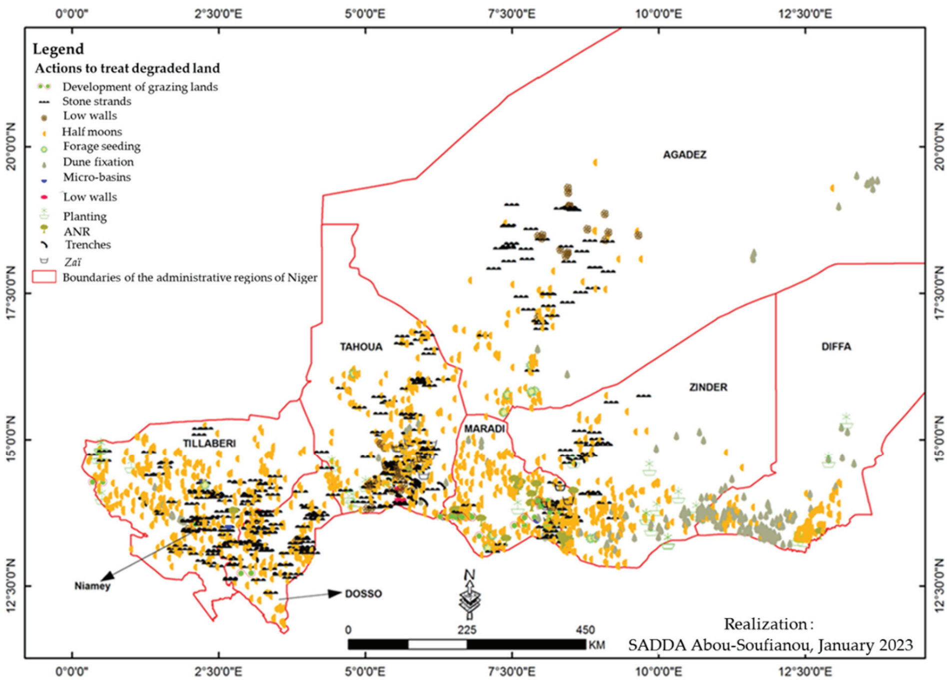

Figure 8. Spatial distribution of geolocated DLRAs in Niger.

The practice of dune fixation is mainly observed in the regions of Diffa, Tillabéri, and Zinder, more marginally in the south-west and south-east of the Agadez region, in the north and east of the Maradi region, and in the east of the Tahoua region. These are the northernmost parts of the country from east to west, most affected by wind erosion leading to sand dune movements. These are also pastoral areas par excellence where pressure on plant resources is very intense, leading to soil denudation. RNA and tree planting practices are widespread, except in the regions of Dosso, Niamey, and Agadez. Niamey is a highly urbanized area not oriented towards rural agricultural activities, while much of the Dosso area is either covered by in-ground plateaus or covered by woody vegetation (W park forest). Fodder sowing is observed everywhere except in the regions of Dosso, Niamey, and Diffa. Dosso and Niamey do not constitute a livestock zone par excellence, and therefore do not have degraded pastoral land. The size of the pastoral area in the Diffa region has probably limited seeding efforts.

Some DLRAs are implemented exclusively in certain regions: low walls in the Tahoua region; trenches in the Tahoua, Zinder, Dosso, and Tillabéri regions; stone barriers in the Agadez, Tahoua, Dosso, and Niamey regions; micro-basins in the Maradi and Tillabéri regions; zaïs in the Maradi and Tahoua regions; and pastoral rangeland development in the Tillabéri, Maradi, and Dosso regions (Figure 8). This specialization is linked to the geomorphological and agroecological characteristics of the regions but also to the requirements of the practices themselves. For example, the stone cordons require the presence of stone, a resource which the regions located on the plateaus and plinths are endowed with, as is the case in Tahoua, Agadez, Dosso, and Tillabéri.

The micro-basins are constructed in rainy areas with relief (Tillabéri) or soils sensitive to linear erosion that can create koris and gullies (Maradi). The zaï are more suitable for DLRAs on the crested soils of agricultural areas (Tahoua) or to optimize organic fertilization on degraded sandy soils (Maradi).

3.4. Mapping the Actors' Role: The State of Niger, a Key Player in the Fight against Land Degradation in Niger

The contributions of the more than 100 stakeholders identified in our database to the 279,074 ha processed by DLRAs can be distinguished according to their "functional" role: (1) as donors (Do), (2) as fund mobilizers (Fm), (3) as operators (Op), and (4) as implementers (Figure 9).

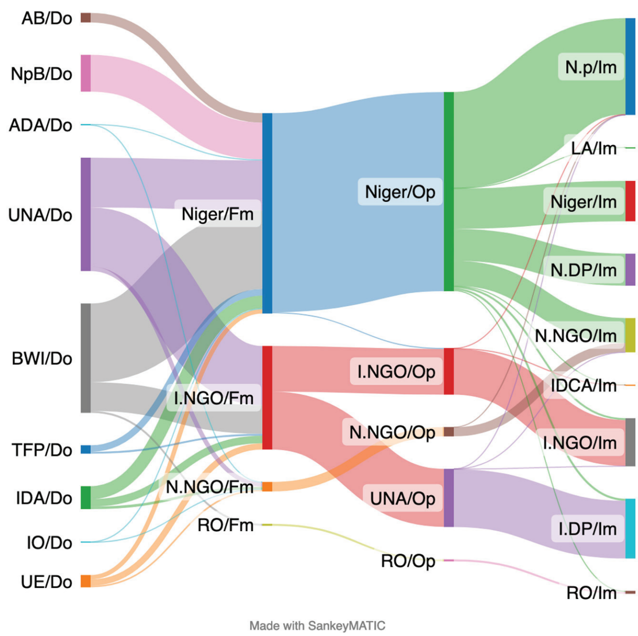

Figure 9. Chain of actors for sustainable land management in Niger. Note: left to right: (1) donors (Do); (2) fund mobilizers (Fm), i.e., an actor who identifies and mobilizes funds; (3) operators (Op), i.e., an actor who puts DLRA in action; and (4) implementers (Im), i.e., an actor who implements DLRAs in the field. Legend: Donors: ADA/Do—African development agencies; IDA/Do— international development agencies; UNA/Do—United Nations' agencies as a donor; AB/Do—African Bank; CB/Do—community banks; NpB/Do—The Niger public budget; BWI/Do—Bretton Woods Institutions; IO/Do—international organizations; TFP/Do—technical and financial partners; EU/Do—European Union (See detail in Table S1). Fund Mobilizers: Niger/Fm—The Niger public authority; I.NGO/Fm—NGOs and international associations; N.NGO/Fm—NGOs and Nigerien associations; RO/Fm—sub-regional organizations (See detail in Table S2). Operators: UNA/Op—United Nations' Agencies; Niger/Op—The Niger as a fundraiser; LA/Op—local authorities; I.NGO/Op— NGOs and international associations; N.NGO/Op—NGOs and Nigerien associations; RO/Op—sub-regional organizations (see detail in Table S4). Implementers: IDCA/Im—International development cooperation agencies; LA/Im—local authorities as an implementer; Niger/Im—The Niger as an implementer; I.NGO/Im—NGOs and international associations as an implementer; N-NGO/Im—NGOs and Nigerien associations; I.DP/Im—international development programmes (see detail in Table S5).

Ten categories of donors financed the implementation of DLRAs in Niger (Table S1) and for various areas (Figure 9). The UN agencies and Bretton Wood institutions are the main donors, whose financing represents, respectively, 36% (100,565 ha) and 34% (96,825 ha) of the total area of DLRAs. The Government of Niger, with its own funds, comes in third place with 12% (35,716 ha) of DLRAs. Other donors (e.g., international agencies, the European Union, African banks, technical and financial partners, African development agencies, community banks, and international organizations) have made funding available to treat 7%, 4%, 3%, and 1%, respectively, of the total area of land treated in Niger.

As an actor involved in the mobilization of funding (Table S2), the Government of Niger plays a key role. Its action has made it possible to treat 63% of the total area. In this role of mobilizing funds, NGOs and international associations are the second most important actor (e.g., 33% of the total area treated is due to their efforts to mobilize funds).

Once mobilized, these funds dedicated to DLRA are put into action by six categories of operators (Table S3). Their contribution varies (Figure 9). Again, in this role, the Government of Niger is the main actor. It has implemented actions covering 63% of the total area treated. The remaining third was made possible by the action of the UN agencies (18%) and the NGOs/international associations (19%). The action of other operators (e.g., national NGOs/associations, sub-regional bodies, and municipalities) constituted less than 4% of the LADA. Development programmes and projects have been the most effective vehicles to put DLRAs into action (Table S4 and Figure 9). The largest areas of DLRA, amounting to 149,137 ha (53%), were implemented under national development projects (e.g., the Climate-Sensitive Agriculture Support Project, the Resilience Building Project to Combat Food Insecurity in Niger, and the SLM Project). International development programmes and projects (e.g., World Food Programme and Action Against Hunger) contributed 19% and 11% of the DLRAs, respectively. In our database, national development programmes and sub-regional projects have very little involvement in SLM actions.

At the very end of the chain of actors (Figure 9), national development projects (e.g., the Community Action Project for Climate Resilience and the Emergency Project in Support of Food Security and Rural Development) were the main contributors to the implementation of the DLRAs (31%) on the ground (Table S6). In contrast, sub-regional development projects, international development cooperation agencies, and local authorities contributed very little to field interventions (merely 1%). The other modalities carried out between 18% and 19% of the total area of DLRAs.

Figure 9 points out the key role of the State of Niger as a fund mobilizer and an operator, supporting more than 60% of the effort in the fight against land degradation in Niger.

4. Discussion

4.1. Traceability and Sharing of DLRA Data in Niger

An effective SLM policy requires a comprehensive and spatially based assessment of the current situation [26]. Our study revealed the existence of a few non-operational sectoral DLRA databases [20,27,28]. Most of the available data on DLRA suffer from a lack of accessibility (most often not organized in a table or database), reliability, and geolocation. However, the vast majority of data are used by some actors to construct indicator tables, graphs, or maps [28,29]. However, this use is limited to each of the actors, without sharing or archiving according to common criteria [20,28,30,31]. Although useful for each of the actors, this fragmentation of knowledge is not up to the challenges, on a national scale, of monitoring and evaluating actions and their impacts, avoiding the repetition of what has already been done, and the necessary coordination of the various actors in their respective roles. This situation is not an asset for policy making [32,33] or practices to ensure the proper monitoring and assessment of land degradation in Niger [20,34].

The effective implementation of a geolocalized data table that allows the traceability of DLRAs is a guarantee of better visibility of actions in the field [35,36] and a better evaluation of the use of SLM practices and the sustainability of project effects [37]. Its value lies in the fact that it can prove valuable in improving knowledge [38], especially if it is used and interpreted within a scientifically rigorous methodological framework [39]. Such a data table would facilitate communication between partners and stakeholders in the development of SLM strategies, programmes and projects [40]. These interactions are also a guarantee of good cooperation between all actors. Their respective actions could be based on the same body of data [25].

In this perspective, the need to access spatially referenced databases with a common architecture has been demonstrated [25] according to a harmonized nomenclature. The choice to build a single data table in this work is based on the absence of such a database. The collection of available data, which are scattered, of heterogeneous quality, and of very different natures and formats [41,42], and then formatting and harmonizing them, was therefore a prerequisite for their processing [43,44]. Based on criteria useful for their traceability, it was possible to set up a national data table integrating both information on geolocated DLRAs and information on the network of actors involved. The national data table, which is probably incomplete, nevertheless has the potential to be a useful source of information for the formulation of recommendations to decision makers in the implementation of strategies for capitalizing on and scaling up DLRA.

The method of construction as well as the final structure of this Niger data table could constitute a replicable model in other countries of the GGW zone. In the future, it can help the various data providers to adapt their own data tables (structure and nomenclature) to feed (automatically or not) the national data table more easily. However, ways must be found to maintain and feed such a spatially referenced data table at the national level in the long term for the spatiotemporal monitoring and assessment [25,28,29,45] of DLRA. One way to do this would be to strengthen the skills of the structures that produce these data so that they can maintain such a database, and then build a central national web portal (or even a regional one in the context of initiatives such as the GGW). Such a portal would make it possible to query the data tables distributed in the various structures in order to generate the national table automatically (in the sense of using the most up-to-date data). This web portal could also make it possible to visualize the data on maps according to a standardized graphic semiology, and to navigate through the data according to a geographical query.

These perspectives raise a number of questions: What is data governance? Which structures should produce the data along the chain of actors, from donors to the entity that executes DLRA on the ground? Where to host such a centralized service? What steps should be taken to ensure that the distributed data tables are compatible with the query on the central service? How can the membership of data-producing structures be increased? etc. If each GGW country were to organize such spatially referenced DLRA data systems, this could help, for example, to feed the regional SIOBAP system (System of Information, Observation, Early Warning and Response) that the Pan-African GGW Agency (PAGGW) is setting up.

4.2. DLRA Adapted to the Needs of the Population and Administrative Regions of Niger

The analysis of the results of the geolocated data table revealed a wide diversity of DLRAs conducted. These results are in line with those of many works carried out in Sahelian environments [6,46–51]. Indeed, each of these techniques is adapted to a specific socio-ecological situation. Among this diversity of DLRAs, our results showed that dug-out structures are the most frequent. These include soil and water conservation and soil defence and restoration work (SWC/SDR). They are adapted to Sahelian and Sudano-Sahelian zones [52]. Several studies have shown the effectiveness of these techniques in improving the productivity of degraded land [53–56]. They are an effective way to better manage water and reduce land degradation [46], and protect vegetation and biodiversity [49], by increasing and stabilizing agricultural, forestry, and forage yields [6]. Other work has also confirmed that these types of excavated structures increase soil moisture and nutrient availability [48] and promote crop growth [50,57–59]. These arguments are consistent with the results of Ado et al. [50], who showed that zaï structures, half-moons, which are widespread in Niger where they were first used in the Tahoua region, allow for the growth and development of sorghum crops on land that is initially ridged and uncultivated. These structures make it possible to increase agricultural production [60] and improve the food security of the population [61–63].

Our results showed that geolocated DLRAs spatially occupy more than the southern half of Niger, corresponding to the agrosylvopastoral production zones [64]. They confirm the widely supported conclusions that the areas of SLM intervention in Niger are located on the part of the continent formed by ancient, strongly granitized, and metamorphosed terrains [65].

4.3. Diversity of the Network of Actors and Importance of Official Development Assistance in the Implementation of DLRAs in Niger

Funding sources are most often mobilized through multilateral and bilateral mechanisms involving technical and financial partners (TFPs) and NGOs [66]. Moreover, it is not uncommon for technical and financial partners to implement their projects and programmes through their own structures and using their own expertise [67].

Our analysis in Niger sheds particular light on the diversity of actors with specific roles. Some of them, such as the State of Niger, play several roles: as a funder, fundraiser, implementing agency, and executor through its own programmes. The State of Niger complements its reduced capacity to finance from its own funds by a very strong mobilization of funds from donors [27,31,67].

Our results also showed that local governments play an important role in SLM in Niger. This is due to the fact that they mobilize a lot of additional funding through twinning with other communes in developed countries or through decentralized cooperation [68–71]. These additional resources for SLM are implemented through medium- and long-term projects. They also make co-financing contributions, often quite substantial, for SLM actions carried out by development projects or by NGOs. Local authorities, in particular communes, provide additional funding by including in their communal development plans and annual investment plans the financing of actions to combat land degradation [67].

Given certain administrative difficulties, many donors have chosen to work directly and exclusively with NGOs and associations. The size of the envelope devoted to SLM work, coupled with this change in policy, has encouraged the emergence of NGOs involved in SLM. Indeed, most of them, especially national ones, mobilize and execute contracts and agreements with national projects and programmes. They constitute a substantial funding force for SLM, as they are able to mobilize and implement funds that other actors do not or no longer have access to. Within the framework of the "do-it-yourself" approach, several funding options exist and are within the reach of local NGOs. In many cases, they lobby and advocate to mobilize funds other than those of national projects and programmes and intervene in the form of real implementing agencies [67,72]. They themselves call on internal expertise and implement many externally funded projects that are not included in the government's investment budget [66]. Additionally, several NGOs and associations are involved in promoting proven SLM practices. On the ground, NGOs are present, especially in food-insecure areas, as they benefit from significant resource allocations [25].

5. Conclusions

Reducing and slowing down land degradation, and rehabilitating or restoring degraded land are key levers in achieving sustainable development for the benefit of populations—particularly those whose livelihood relies on ecosystem services. Combatting land desertification has been declared a national priority in the Niger, echoing target 15.3 of the SDGs. Based on a collection of public data held by different entities, we have built a unique database consisting only of georeferenced data, containing all the information not only on DLRA, but also on the actors and their roles as donors, fund mobilizers, operators, and implementers. This is a clear choice based on the objective of our work. We are aware that not all field actions are itemized. However, our work demonstrates the added value of creating such a georeferenced database management system in order to (i) deploy targeted sustainable land management initiatives that complement both past and ongoing actions (thus avoiding multiple actions in the same place) and (ii) synergize all the stakeholders. Nevertheless, the task of identifying, harmonizing/standardizing, and geolocalizing DLRAs on a country-wide scale is considerable. The work in the Niger is unfinished but offers a roadmap towards consolidating these achievements and ensuring their transferability to other countries. The creation and continuous feeding of a database management system must also be undertaken. To this end, raising awareness and mobilizing all stakeholders to contribute collaboratively to such a common dataset represents a major challenge.

However, the efforts involved in such an undertaking are small compared to the benefits of acquiring such a database. It will help in assessing and monitoring the contribution of DLRAs to the SDGs, and thus give value and visibility to the role of each stakeholder. The establishment of scientific observatories anchored in the territories can meet this ambition.

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Article

A Participatory Approach to Assess Social Demand and Value of Urban Waterscapes: A Case Study in San Marcos, Texas, USA

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Abstract: Waterscapes can have meaningful benefits for people's wellbeing and mental health by helping them feel calmer and more connected to nature, especially in times of stress such as the COVID-19 pandemic. The waterscapes along the San Marcos River (Texas, USA) provide economic, social, environmental, and emotional benefits to the surrounding community. To assess the social demand for and emotional experiences in these blue spaces, we used a new framework called Blue Index that collects noncontact data from photo stations. From 10 photo stations across different waterscapes, we collected and analyzed 565 volunteer assessments from May 2021 to March 2022—during the COVID-19 pandemic and following the reopening of riverside parks. Most respondents (57%) indicated they spend more time at the river than they did before the onset of the pandemic. Moreover, 93% of respondents agreed that the waterscape they were visiting represented a refuge from stress and isolation caused by COVID-19. Overall, people valued waterscapes for ecological benefits and relationships with the place, rather than for recreation and tourism. Emotions experienced at all 10 waterscapes were overwhelmingly positive. Statistical tests revealed that higher positive emotions were significantly associated with biophysical perceptions of flow, cleanliness, and naturalness. Our results demonstrate that the benefits of blue spaces derive from an interrelated combination of ecosystem and mental health. The new Blue Index approach presented here promotes participatory land management through noncontact community engagement and knowledge coproduction.

Keywords: urban blue space; relational values; community science; COVID-19; participatory research; social–ecological systems; mixed methods; emotional experiences

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1. Introduction

Aquatic ecosystems are being degraded at an alarming rate [1,2]. A range of threats to freshwater ecosystems including climate change, land-use change, groundwater pumping, and impoundments resulted in an 83% loss of overall freshwater biodiversity from 1970 to 2014 [2,3]. This degradation of aquatic ecosystem health along with the ecosystem services they provide has negative consequences (direct and indirect) on human health [4,5]. Commonly cited negative consequences include wildlife habitat destruction, impaired water quality, flooding, reduced recreation, and loss of tourism; however, the health and appearance of aquatic ecosystems can also impact mental health and overall human wellbeing [6–8]. The focus of this article is on this less-studied, psychological aspect of aquatic ecosystems.

Rivers, lakes, and wetlands are freshwater ecosystems but can also be conceptualized as blue spaces or waterscapes. Blue spaces are defined as "health-enabling places and spaces, where water is at the center of a range of environments with identifiable potential for the promotion of human wellbeing" [9]. Maintaining healthy blue spaces promotes positive feedback between environmental health and public health [8]. The waterscape refers to visual and nonvisual elements of the landscape, much like the term riverscape has been used in the literature [10]. Waterscape is broader than riverscape because it also includes lakes and wetlands, which are present in this case study. Blue spaces and waterscapes are synonymous [11], and we use the terms interchangeably depending on the context of the relevant literature.

The benefits of blue spaces and waterscapes are particularly needed in cities with heightened stresses from urban heat islands, poor air quality, traffic, noises, and technological worries. Urban waterscapes can also promote community health and ensure equitable access to ecosystem services within a city [5,7,9]. While several studies have documented the mental and physical benefits of waterscapes [6,12], cultural and emotional aspects of human interaction with water are rarely quantified and even less frequently incorporated into meaningful action or policy [13–16]. These aspects of interaction, however, are meaningful and can guide the sustainable management of urban waterscapes [17].

Understanding relationships between people and nature is essential to the sustainable management of social–ecological systems (SESs) [7,13,18,19]. SESs refer to the systems formed through complex and dynamic interactions and interrelations between people and nature [19,20]. Studying the social demand of SESs (i.e., social actors' reasons for visiting/behaviors, preferences, perceptions, and values) can inform those managing tradeoffs or aiming to incorporate community/stakeholder knowledge in policy [20]. SES research often collects data through stakeholder perspectives that influence their interactions with the landscape [21–23].

The connections people have with places, especially natural places, can have measurable effects on people's overall wellbeing. A greater spatial extent of urban green space within a city and proximity of residency to green space has been shown to increase the restorative potential of landscapes and reduce negative emotional experiences [15,23–25]. The relationship between exposure to nature and emotional wellbeing has been widely researched, although its mediators (e.g., type of activity and restorative experience) are less documented [26]. Most research on nature and health has investigated the role of green spaces [27]. However, multiple studies have concluded that people prefer blue spaces to green spaces when seeking relaxation or restoration [28–30]. Nichols [6] (p. 20) described the unique ability of water to provide relaxation, peace, or higher cognitive functions collectively as "Blue Mind". "Blue Mind" refers to these mental benefits of water, while "Red Mind" refers to stress, fear, or anxiety around water. The ability of waterscapes to produce "Blue Mind" may be dependent on waterscape features, SES values, and personal meanings. Several studies investigating the role of blue spaces on wellbeing found that the therapeutic benefits of place are variable and subjective and are largely determined by the symbolic meaning of place [31–33]. Numerous therapy initiatives are centered around interaction with blue spaces [33–36].

Rivers as SESs provide a diverse combination of ecosystem services, including social–cultural benefits [4,21]. A review of cultural ecosystem service measurement techniques found that spiritual and cultural symbolism and meaning of place are often underrepresented in ecosystem services valuations [37]. Furthermore, laypeople and scientists often have different conceptions of ecosystem services and the framework of evaluation [38–40]. These limitations to the application of the ecosystem services framework have led many, especially cultural geographers, to consider expanding the scope of information that is considered in nature–human relationships [41,42].

Ecosystem values do a better job of uncovering social–ecological dynamics of waterscapes [7]. Because values usually rely on interaction with others, we use the term "SES values" to capture how values for waterscapes are based both on nature–human and social relationships. The literature regarding SES values often gets stuck in a dichotomy of intrinsic vs. utilitarian values [42]. Utilitarian values are those assigned to an ecosystem for a specific means to an end and are derived from human-centered motivations for using or visiting a place. Intrinsic values are biospheric and value the ecosystem in itself. This dichotomy has led to a "discourse of battle" in conservation between benefits to people vs.

benefits to nature [38,43]. This divide, however, is not reflective of the ways humans make decisions and interact with the world [44,45]. Relational values highlight the restorative nature and responsibilities that exist in SES through relationships and modes of interaction with place [13] and have been introduced as a "third class of values" alongside intrinsic and utilitarian values [46].

Relational value statements depend on aspects of identity, kin, emotions, responsibility, community, health, or a combination of these factors [38]. Depending on the type of statement used (or emotion considered), different meanings of relational values may be expressed. Relational values go beyond traditional monetary quantification and are essential to capture non-Western conceptions of nature–human relationships [47]. Relational values tend to situate personal relationships within a subjective framework of meaning, rather than through a strict definition [17,31].

Blue spaces represent opportunities to promote relational values and "urban commons" by encouraging shared responsibilities, stewardship, and equitable access to waterscapes [7,8,48,49]. Measuring subjective experiences and SES values may reveal cultural and subjective meanings, which are valuable insights for land-use and water resources planning. There is an increasing social demand for interaction with waterscapes and the ecosystem services they provide, but this increased demand includes necessary tradeoffs between different stakeholders and various bundles of ecosystem services [40,50–52]. Taking into account these complex dimensions of blue space SESs, Jeffery and Davidson [53] introduced the Blue Index framework to increase public participation in urban waterscape management. The Blue Index assessment quantifies the effect of waterscapes on emotional health to guide the design of public waterscapes and coproduce solutions for tradeoffs in water management. The framework uses spatiotemporal photos to document changes over time and represent relationships with waterscapes. Other studies have also shown that photo databases embody cultural aspects of SES values and relationships with place [54,55]. Here, we expand on the Blue Index participatory framework and its use of photo stations to assess emotional experiences in response to waterscapes, social demand for these waterscapes, and broader SES dynamics.

The coronavirus pandemic (COVID-19) has provided researchers with a unique opportunity to make observations about the ways people interact in nature to cope with stressful events, particularly when normal opportunities/practices are removed or unavailable. The literature published on how much time spent in nature in response to COVID-19 has produced mixed results. While the frequency of outdoor excursions and distance traveled to experience the outdoors has declined in some places because of COVID-19 restrictions [56], some studies have shown that the visitation of local urban greenspaces has increased [57]. When studying urban green spaces and emotions in the context of the COVID-19 pandemic, Samus et al. [58] found that the degree to which people felt connected to nature predicted their positive emotions during COVID-19 lockdowns. Two international surveys found that there is a global increase in the frequency of using blue/green spaces and an increased appreciation for these spaces during and after COVID-19 lockdowns [59,60].

This study used mixed methods and an SES framework to quantify and characterize urban waterscape interrelationships. The guiding research question was the following: "How do people feel, perceive, value, and interact with waterscapes, and what biophysical differences influence these experiences"? This question was investigated through a "Blue Index" assessment on social demand for and emotional experiences in response to waterscapes. Because of the unique challenges presented by COVID-19 and the need for spatially explicit data, assessments were administered remotely through strategically placed stations with quick response (QR) codes along an urban waterscape consisting of rivers, wetlands, and a spring-fed lake. Participants also submitted photos (taken from the same distance, perspective, and angle) with their assessments to ensure responses were spatially accurate and to create a waterscape photo database.

2. Materials and Methods

2.1. Study Area

Hays County in Texas (USA) grew by 55% from 2000 to 2010 [61] and by another 54% from 2010 to 2020 [62], making it the fastest growing county in the nation (by percent) over this period with a minimum population of 100,000. San Marcos—the county seat—has been one of the fastest growing cities in the nation (by percent) over the past decade with an ~8% annual population increase in recent years [63]. This rapid population increase at the city and county levels has been accompanied by intense development and enhanced urban stresses. Over this period, the city of San Marcos and its river have also become a major regional, national, and even international tourist destination [8,64,65].

The San Marcos River (SMR) along with its tributaries, wetlands, and lake are centrally located within the city of San Marcos (Figure 1) and represent a social–ecological system (SES). These waterscapes provide a multitude of ecosystem services that benefit the surrounding communities [7,8]. The spring-fed river ecosystem is a habitat for several endangered species and possesses important biodiversity [64,66]. In the coming years, the San Marcos River SES will be challenged by tradeoffs between ecosystem health and development [7]. These future tradeoffs make San Marcos a valuable case study for measuring social demand of urban blue spaces and community preferences for future land and water management. An analysis of community SES values and mental health is necessary to provide reflexive decision making in these tradeoff scenarios. The data collection for this study took place at 10 sites along the San Marcos River, its headwaters and wetlands at Spring Lake, and one of its tributaries. See Appendix A for site descriptions of these 10 waterscapes.

Figure 1. Study area map displaying locations of numbered Blue Index photo stations at waterscapes in San Marcos, Texas, USA. Each numbered site is described in Appendix A.

2.2. Data Collection

The social demand and emotional experiences of waterscapes in San Marcos were measured through volunteer assessments (also known as questionnaire surveys) and photos at various sites along the San Marcos River, including its headwaters, which form Spring

Lake, and its adjacent wetland ecosystems (Figure 1). Assessment stations were spatially distributed to capture multiple degrees of different waterscape characteristics, including extent of development and optical water quality, to conduct a natural experiment across different waterscapes.

Data were collected over a 10 month period (29 May 2021 to 4 March 2022) using 10 Blue Index photo stations. Each station consisted of an L-shaped frame attached to an existing bridge or post and an acrylic sign (15 cm × 15 cm) with instructions for submitting photos and participating in the assessment. This structure forms a fixed photo station where a participant can place their cell phone and submit a photo of the waterscape they are visiting (Figure 2). Participants accessed the assessment through a quick response (QR) code posted on the acrylic sign. Participants were required to have a cell phone and access to cellular data to use the Internet, as almost all of the study sites were in public parks without free Wi-Fi.

Figure 2. Blue Index photo station (**left**) attached to existing bridge at City Park (Site #3, (**right**)).

2.3. Assessment Design

The assessment was designed on the basis of previous research from and in collaboration with the Blue Index project [53] (https://blueindex.org/ accessed on 10 May 2023). No risks were anticipated as a result of participation in this study (IRB #7792). All subjects gave their informed consent and permission to use their photo before they participated in the assessment. The assessment consisted of 18 questions and a photo submission. Photos were collected to track landscape characteristics over time and to complement the information provided in assessment. Questions in the assessment consisted of (1) reported emotional experiences at the waterscape, (2) perceptions of waterscape characteristics including cleanliness, naturalness, accessibility, and flow, (3) perceptions of relaxation and refuge, (4) values based on which river function was deemed most important, (5) types of activity and frequency of visits, (6) relationships with waterscapes before and after the onset of COVID-19, and (7) demographics of participants including permanent and temporary residency. The full assessment is in Appendix B. All assessment responses were self-reported and based on perceptions and personal experience. Measures of emotional experience were collected on a five-point Likert scale for six emotions that represent a diverse subset of Plutchik's [67] Wheel of Emotions: joy, serenity, fear, disgust, sadness, and amazement. These emotions represent different "spokes" on the wheel of emotions and were selected to represent general categories of emotions that participants potentially experienced. Participants had the opportunity to write in any emotions they experienced that were not represented by these six choices. Participants had several opportunities to provide their own responses including additional emotions they felt or additional comments about each waterscape.

2.4. Analyses and Techniques

Assessments were distributed and archived using the Qualtrics online survey platform. We analyzed data using Excel statistics and R Studio. Data were compared among four types of waterscapes (lake, wetland, perennial river, and intermittent tributary) to determine how relationships with waterscapes varied with biophysical settings. These four primary locations had large and comparable assessment sample sizes. We conducted a secondary analysis using all 10 sites and acknowledge that these statistical tests with smaller sample sizes are less meaningful. We used Kruskal–Wallis, pairwise Wilcoxon ranked sum, and Spearman's rho, all nonparametric statistical tests, to analyze how emotions and perceptions were influenced by waterscape type and values. Kruskal–Wallis tests analyzed variance between groups in the nonparametric dataset, pairwise Wilcoxon tests identified which groups were different, and Spearman's rho measured the strength of correlation between variables. Nonparametric statistics were utilized due to the non-normal distribution of the data. Thirdly, we performed a qualitative text mining analysis of additional comments to complement statistical conclusions and provide information about relationships with waterscapes that went uncaptured by closed, quantitative questions.

3. Results

3.1. Social Demand and Emotional Experiences of Waterscapes

Data collection took place from 29 May 2021 to 4 March 2022. There were a total of 870 responses. After removing entries that did not answer the questions about emotions and/or uploaded a photo, 565 responses remained viable for analyses. Across the 10 sites, response counts ranged from 12 to 98 usable assessments at each site.

Descriptive statistics across sites, as well as a breakdown of demographic characteristics for the entire sample, revealed a wide range of social actors that visit the San Marcos River social–ecological system (SES) (Table A1). Most river visitors were young college students who identified as residents, but more than one-quarter of respondents were older than 35. More than half of respondents were not permanent residents, meaning they were likely a tourist/visitor or a nonresident student. Most of the river visitors frequented the SES at least monthly, with one-third visiting it at least weekly (Table A1). Over 9% of participants at the tributary visited daily, likely because of the photo station's position on a walking path.

When asked about what they valued most about the waterscape, almost half of the respondents chose relational values (45.7%) while a similar percentage chose intrinsic values (44.6%). Only 9.6% of participants chose utilitarian values as the most important. Overall, positive emotions were ranked as more intense than negative emotions (Figure 3). Results about how COVID-19 has impacted relationships with waterscapes revealed that the pandemic has shifted perceptions and visitation patterns. Over half (56.8%) of respondents indicated that they spent more time at the river at the time of the assessment than they did before the onset of the pandemic. Furthermore, 93% of respondents agreed that the waterscape they were visiting represented a refuge from stress and isolation caused by COVID-19. We did not find any statistically significant differences in social demand among participants based on sociodemographic information.

We conducted statistical tests with SES value as the independent variable. Those that expressed a utilitarian value reported significantly lower average intensity of joy, serenity, and relaxation (Table 1). Pairwise Wilcoxon tests revealed that perceptions of flow, cleanliness, naturalness, and feelings of refuge were significantly associated with expressed SES value (Table 2).

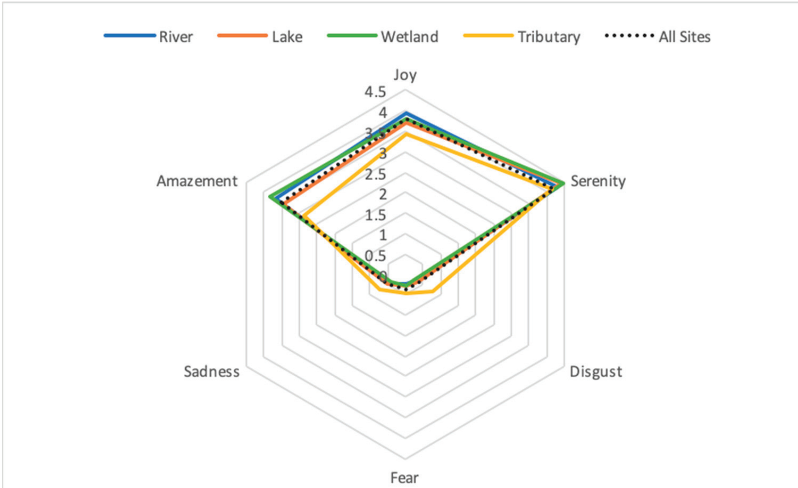

Figure 3. Distribution of mean emotional experiences across waterscape settings.

Table 1. Average scores for dependent variables for all sites organized by SES value.

	Joy	**Serenity**	**Disgust**	**Fear**	**Sadness**	**Amazement**	**Relax**	**Access**	**Flow**	**Clean**	**Natural**	**Refuge**
Overall	3.80	4.23	0.40	0.35	0.49	3.52	4.08	4.44	4.12	4.08	4.29	4.38
Intrinsic (n = 227)	3.80	4.34	0.36	0.33	0.52	3.58	4.15	4.47	3.91	3.87	4.39	4.40
Relational (n = 233)	3.90	4.28	0.37	0.34	0.47	3.49	4.15	4.49	4.37	4.28	4.40	4.48
Utilitarian (n = 49)	3.38	3.61	0.53	0.28	0.36	3.25	3.73	4.14	4.31	4.37	3.41	3.98

Table 2. Results of Kruskal–Wallis and Wilcoxon post-tests (all 10 sites) investigating emotional experiences and perceptions as a function of SES value: intrinsic (I), utilitarian (U), and relational (R). Bold values were significant at an alpha of 0.05.

Dependent Variable	***p*-Value of Kruskal–Wallis Test**	***p*-Values of Pairwise Wilcoxon Test by SES Value**			**Summary of Significant Differences**
Joy	**0.009**		I	R	Utilitarian lower than relational or intrinsic
		R	0.35	-	
		U	**0.05**	**0.01**	
Serenity	**0.009**		I	R	Utilitarian lower than relational or intrinsic
		R	0.59	-	
		U	**0.003**	**0.006**	
Disgust	0.57		I	R	Utilitarian higher than relational or intrinsic
		R	0.35	-	
		U	**0.05**	**0.01**	
Fear	0.81		I	R	
		R	0.67	-	
		U	0.74	0.56	
Sadness	0.98		I	R	
		R	1	-	
		U	0.86	0.85	
Amazement	0.45		I	R	
		R	0.43	-	
		U	0.25	0.46	
Relaxation	**0.04**		I	R	Utilitarian lower than relational or intrinsic
		R	0.41	-	
		U	**0.03**	**0.02**	

Table 2. *Cont.*

Dependent Variable	*p*-Value of Kruskal–Wallis Test	*p*-Values of Pairwise Wilcoxon Test by SES Value			Summary of Significant Differences
Access	0.12		I	R	Utilitarian lower than relational
		R	1	-	
		U	0.06	**0.05**	
Flow	**<0.001**		I	R	Intrinsic lower than relational
		R	**<0.001**	-	
		U	0.06	0.62	
Clean	**0.002**		I	R	Intrinsic lower than relational or utilitarian
		R	**<0.001**	-	
		U	**0.03**	0.79	
Natural	**<0.001**		I	R	Utilitarian lower than intrinsic or relational
		R	0.7	-	
		U	**<0.001**	**<0.001**	
Refuge	**0.009**		I	R	Utilitarian lower than intrinsic or relational
		R	0.17	-	
		U	**0.03**	**0.002**	

3.2. Differences among Waterscape Biophysical Settings

There were key differences in social demand and emotional experiences among waterscape biophysical settings: lake, wetland, perennial river, and intermittent tributary. We chose one of the seven river settings (Sewell Park) to represent the river as it had a similar sample size to the other three settings. Kruskal–Wallis tests were conducted to determine whether statistically significant differences exist between waterscape settings (Table 3). Several variables were found to vary with setting, with the intermittent Purgatory Creek (Tributary) typically being the most distinct from other settings. Disgust was higher, but amazement and perceptions of refuge were lower for Purgatory Creek than other settings (Figure 3). Participants at the wetland demonstrated significantly higher reports of joy and serenity than those at the tributary. The tributary sight also produced higher sadness than the lake and wetland.

Table 3. Relationships between emotions/perceptions and waterscape setting: San Marcos River (R), Spring Lake (L), Spring Lake Wetlands (W), and Purgatory Creek tributary (T). Bold values were significant at an alpha of 0.05.

Dependent Variable	*p*-Value of Kruskal–Wallis Test	*p*-Values of Pairwise Wilcoxon Tests				Summary of Significant Differences by Waterscape
Joy	**0.01**		R	L	W	Joy was higher at wetland than tributary
		L	0.16	-	-	
		W	0.78	0.22	-	
		T	0.73	0.27	0.04	
Serenity	**<0.001**		R	L	W	Serenity was higher at the wetland than the tributary
		L	0.36	-	-	
		W	0.27	0.82	-	
		T	0.46	0.10	**0.07**	
Sadness	0.078		R	L	W	Higher at tributary than lake or wetland
		L	0.70	-	-	
		W	0.84	0.85	-	
		T	0.06	**0.03**	**0.04**	
Amazement	**0.009**		R	L	W	Lowest at tributary
		L	0.91	-	-	
		W	0.39	0.33	-	
		T	**0.01**	**0.01**	**0.001**	
Disgust	**<0.001**		R	L	W	Highest at tributary
		L	0.35	-	-	
		W	0.95	0.38	-	
		T	**<0.001**	**0.001**	**<0.001**	
Fear	0.283		R	L	W	Higher at tributary than river
		L	0.25	-	-	
		W	0.71	0.44	-	
		T	**0.02**	0.23	0.06	

Table 3. *Cont.*

Dependent Variable	*p*-Value of Kruskal–Wallis Test	*p*-Values of Pairwise Wilcoxon Tests				Summary of Significant Differences by Waterscape
Flow	**<0.001**		R	L	W	River higher than all; lake higher than wetland and tributary; wetland higher than tributary; tributary lower than all
		L	**<0.001**	-	-	
		W	**<0.001**	**0.12**	-	
		T	**<0.001**	**<0.001**	**<0.001**	
Clean	**<0.001**		R	L	W	River higher than all others; lake higher than wetland; wetland higher than tributary; tributary lower than all others
		L	**0.001**	-	-	
		W	**<0.001**	**0.01**	-	
		T	**<0.001**	**<0.001**	**<0.001**	
Natural	**<0.001**		R	L	W	Wetland and tributary higher than river and lake setting
		L	0.73	-	-	
		W	**<0.001**	**0.003**	-	
		T	**0.002**	**0.01**	0.91	
Refuge	**<0.001**		R	L	W	Tributary lower than all other settings
		L	0.80	-	-	
		W	0.92	0.78	-	
		T	**<0.001**	**<0.001**	**<0.001**	
Access	0.09		R	L	W	Tributary lower than river
		L	0.18	-	-	
		W	0.32	0.65	-	
		T	**0.02**	0.25	0.09	
Relative restoration (relaxation)	**<0.001**		R	L	W	Tributary lower than all other settings
		L	0.11	-	-	
		W	0.76	0.19	-	
		T	**<0.001**	**0.01**	**<0.001**	

All four settings had significantly different perceptions of flow (Table 3, Figure 4). Participants perceived the intermittent tributary setting (Site #11) as less flowing, less clean, and more natural than all other settings. The tributary setting also had a significantly lower relaxation and refuge effect (Table 3). Reasons for visiting varied across settings, but common reasons for visiting showed that ecosystem functioning and relationships with place were prioritized over recreation, with frequent reasons for visiting including relaxing/stress relief/meditation and wildlife viewing/exploring nature (Table 4). An important note is that Spring Lake and its adjacent wetlands are protected ecosystems where public swimming and fishing are not permitted. The intermittent tributary does allow swimming and fishing, but its conditions for these activities are not ideal.

Figure 4. Distribution of mean perceptions of waterscape characteristics across waterscape settings.

Table 4. Reasons for visiting across four waterscape settings. The three most common reasons for visiting each setting are shaded.

Reason for Visiting	River (*n* = 91)	Lake (*n* = 98)	Wetland (*n* = 89)	Tributary (*n* = 82)	All Settings (*n* = 565)
Art/photography	10	6	9	0	38
Community event/music event/special occasion	3	6	1	1	29
Commuting	5	1	1	2	10
Dog walking	19	3	5	9	45
Exercising	28	7	16	33	45
Family outing/date/socializing	4	30	37	23	182
Fishing	5	0	0	0	8
Relaxing/stress relief/meditating	40	20	30	33	199
Solitude	21	5	15	14	90
Water sport/tubing	20	2	2	2	54
Wildlife viewing/exploring nature	35	35	47	19	207
Work/school	43	37	24	10	188

3.3. Comparative Analysis of Sites along the Perennial Mainstem San Marcos River

We compared seven stations along the perennial mainstem San Marcos River (Sites #2–8) to hold waterscape setting (and flow) as a constant and test the effect of other variables on social demand. Other than site 6 (Sewell Park), the data from these river stations were not included in Section 3.1 due to small sample sizes. While this section is a relatively short segment of the river, it is diverse in its degree of maintenance, development, geomorphology, and ecological features (Figure 1). Several public parks offer river access points, but these also vary in their degree of accessibility and visitation frequency.

The seven perennial river sites varied in aspects of emotional experience, SES values, and perceptions (Table 5). The variability in reasons for visiting waterscapes reflected the diverse settings of the San Marcos River (Table 6). While relational values were the most frequent SES value across all river sites, the distribution of values varied according to site. Again, positive emotions were experienced to a greater extent than negative emotions across sites (Figure 5), and negative emotions were often qualified with a concern for the river's ecological integrity. It is worth noting that the two sites where fear was ranked the highest (#3 and #7) were both located on bridges.

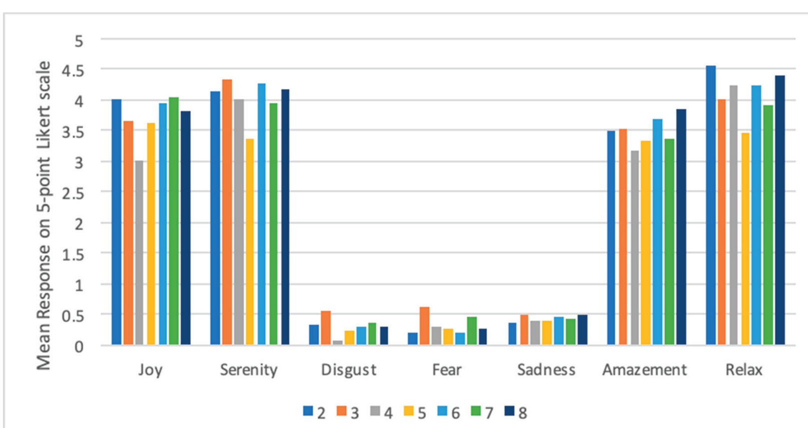

Figure 5. Average intensity of emotional experiences across perennial sites along the San Marcos River. Chart legend: City Park (2), City Park on Bridge (3), Rio Vista Island (4), Rio Vista Park (5), Sewell Park (6), Ramon Lucio Park (7), and Wilderness Park (8).

Table 5. Comparative analysis of perennial river sites along the upper San Marcos River (SMR).

	City Park (#2)	City Park Bridge (#3)	Rio Vista Island (#4)	Rio Vista Park near Rapids (#5)	Sewell Park (#6)	Ramon Lucio Park (#7)	Wilderness Park (#8)
# of Responses	32	48	12	26	91	59	27
Mean emotional scores where 5 represents the highest rating							
Joy	4.03	3.65	3.00	3.62	3.96	4.05	3.81
Serenity	4.16	4.33	4.00	3.38	4.29	3.97	4.18
Disgust	0.33	0.58	0.09	0.24	0.32	0.36	0.32
Fear	0.20	0.64	0.30	0.27	0.22	0.46	0.29
Sadness	0.37	0.49	0.42	0.42	0.46	0.43	0.50
Amazement	3.5	3.53	3.17	3.35	3.68	3.36	3.85
Mean score of perceptions of waterscape characteristics where 5 represents the highest rating							
Relaxation	4.55	4.00	4.25	3.46	4.24	3.91	4.41
Access	4.71	4.46	4.27	4.39	4.55	4.54	4.67
Flow	4.81	4.54	4.64	4.78	4.91	4.57	4.96
Clean	4.94	4.15	4.82	4.83	4.65	4.31	4.89
Natural	4.16	4.52	4.18	3.35	3.94	4.26	4.59
Refuge	4.68	4.35	4.73	4.26	4.50	4.30	4.63
SES value frequency							
Intrinsic	9	19	2	3	24	19	7
Relational	19	24	8	5	51	31	17
Utilitarian	3	4	1	13	11	2	2

Table 6. Reasons for visiting across all sites along the San Marcos River (SMR).

	City Park (#2)	City Park Bridge (#3)	Rio Vista Island (#4)	Rio Vista Park near Rapids (#5)	Sewell Park (#6)	Ramon Lucio Park (#7)	Wilderness Park (#8)
Art/photography	4	5	0	1	10	4	4
Community event/music event/special occasion	3	3	0	4	3	1	0
Commuting	1	1	0	0	5	1	0
Dog walking	2	5	0	2	19	9	5
Exercising	13	11	0	6	28	17	10
Family outing/date/socializing	14	17	1	3	4	21	8
Fishing	1	1	0	0	5	2	0
Relaxing/stress relief/meditating	16	16	1	5	40	24	14
Solitude	8	8	1	3	21	8	7
Water sport/tubing	8	8		4	20	1	6
Wildlife viewing/exploring nature	12	15	1	5	35	25	15
Work/school	13	12	8	17	43	12	12

Ranked correlation and Spearman's Rho revealed that waterscape characteristics were significantly associated with emotions (Table 7). Flow, cleanliness, and naturalness had a positive association with joy, serenity, amazement, and relaxation. Perceptions of cleanliness and whether the waterscape is a refuge were significantly associated with all emotions. Perceptions of flow significantly predicted joy, serenity, sadness, fear, and amazement (Table 7). Access only had a significant association with relaxation, meaning higher perceptions of access were not associated with higher intensity of emotional experiences.

Table 7. Results of Spearman's rho (ρ) ranked correlation test. Bolded variables were significantly associated with the dependent variable at the 0.05 alpha level.

Dependent Variable	Predictor Variables	Spearman's Rho	*p*-Value
Joy	Access	0.1	0.11
	Flow	0.18	0.003
	Clean	0.28	<0.001
	Natural	0.24	<0.001
	Refuge	0.38	<0.001
Serenity	Access	0.05	0.43
	Flow	0.2	<0.001
	Clean	0.21	<0.001
	Natural	0.22	<0.001
	Refuge	0.42	<0.001
Disgust	Access	−0.10	0.14
	Flow	−0.10	0.15
	Clean	−0.22	<0.001
	Natural	−0.11	0.11
	Refuge	−0.15	0.02
Fear	Access	−0.02	0.78
	Flow	−0.18	0.008
	Clean	−0.17	0.009
	Natural	−0.11	0.1
	Refuge	−0.21	0.001
Sadness	Access	−0.03	0.6
	Flow	−0.06	0.39
	Clean	−0.17	0.008
	Natural	−0.16	0.01
	Refuge	−0.18	0.005
Amazement	Access	0.1	0.1
	Flow	0.16	0.01
	Clean	0.25	<0.001
	Natural	0.2	0.001
	Refuge	0.39	<0.001
Relaxation	**Access**	0.18	0.003
	Flow	0.23	<0.001
	Clean	0.31	<0.001
	Natural	0.22	<0.001
	Refuge	0.5	<0.001

3.4. Qualitative Text Mining Analysis

The qualitative analysis was based on text mining of optional comments left by participants and additional emotional experiences mentioned in the assessment (see Appendix D for all comments). In addition to the six emotions included, the participants could write in their own emotions and rank their intensity. Common additional emotions mentioned included nostalgia, happiness, and peace (Table 8).

Table 8. Most mentioned additional emotions listed in the assessment.

Emotion	**Number of Times Mentioned**
Peace/peaceful	9
Happy/happiness	6
Nostalgic/nostalgia	6
Love	3
Wonder	3
Relaxation/relaxing	3
Appreciation	2
Excitement	2
Hope	2
Pride	2

Participants could also leave additional comments at the end of the assessment. The most common keywords in these additional comments were related to water clarity, degree of naturalness, the interaction of people and landscapes, and noise (Table 9). A word cloud shows the most common words from comments (Figure 6). Most comments were positive, although some people expressed negative emotions that stemmed from disapproval of how others treat the waterscape. Several people correctly identified species by sight. Others commented on seasonal or other temporal changes to optical water quality, vegetation density, and shoreline composition (e.g., "I feel the water color has been impacted by ongoing construction and winter time"; "My favorite time to come here is in the fall or winter when there are less people in the water which causes the water and sediment to be less disturbed"). One comment mentioned the fact that the river has been inhabited by humans for over 12,000 years. Another noteworthy comment was the following: "We find the waters of the SM river to have a certain magic to them—the history, the color, the constant temp—it's spiritual."

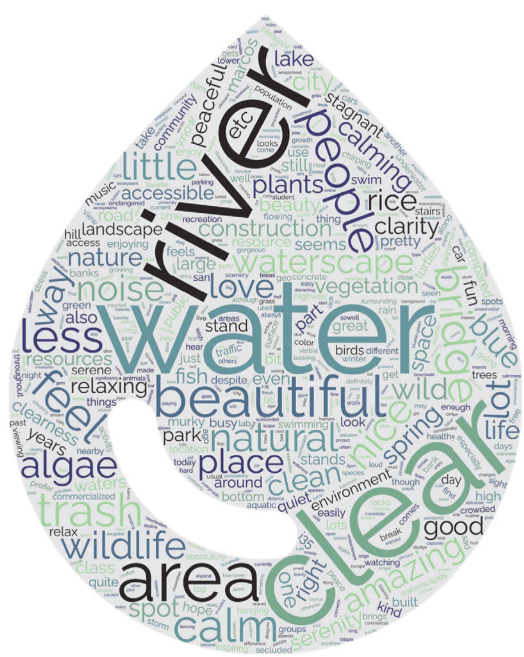

Figure 6. Word cloud showing the frequency of key words from additional comments left by participants across all settings.

Table 9. Keywords with the highest frequency from additional comments left by participants at each site.

Setting	Most Common Keywords
River setting (Sewell Park)	1. Water 2. River 3. Rice 4. Wild 5. Clear
Lake setting	1. Water 2. Clear 3. Beautiful 4. Lake 5. Blue
Wetland setting	1. Clear 2. Noise 3. Water 4. Natural 5. Wildlife
Tributary setting	1. Water 2. Beautiful 3. Stagnant 4. Algae 5. Area
Across all settings	1. Water 2. River 3. Clear 4. Beautiful 5. People

4. Discussion

4.1. Nature–Human Relationships and SES Values in Blue Spaces

Our results show that San Marcos waterscapes, for most visitors, are valued more for their habitat provision or opportunities for connection with nature than for recreation or development opportunities. The locals and nonlocals alike expressed a reverence for the wildlife, optical water quality, and educational opportunities that the river ecosystem accommodates. Statistical tests demonstrated that perceptions of biophysical and social characteristics of waterscapes are significantly associated with emotional experiences. The degree of perceived cleanliness and naturalness had a positive association with higher positive emotions. This supports the finding that the benefits of blue spaces are in part determined by visual landscape features [39,68].

Additionally, Wilcoxon tests revealed that both emotional experiences and waterscape perceptions varied as a function of SES value. Those expressing a utilitarian value experienced significantly lower levels of joy, serenity, and relaxation, and they reported significantly higher levels of disgust. SES values were also significant in predicting perceptions of flow, naturalness, accessibility, cleanliness, and whether the blue space represented a refuge from stress. Those that expressed utilitarian values often saw places as less natural and less of a refuge.

Comparative analyses of sites along the San Marcos River (SMR) revealed patterns of interaction and SES values. The SMR sites exhibited varying degrees of development, recreational opportunities, and traffic noise. These factors were often reflected in comments, SES values, and reported reasons for visiting. For example, Sewell Park is located on Texas State University campus and caters to social and recreational activities. Relational values were most common here, and the most common reason for visiting was relaxing/stress relief/meditation. This reflects the intended scene of Sewell Park, which is an on-campus blue space and refuge from the stresses of urban living or attending school [8]. The presence of healthy blue spaces on university campuses and visiting them for just 10 min a day can significantly improve the mental health outcomes of college students [69,70].

Wilderness Park (#8) is a more isolated and less developed location. Because of its position off the main trail among a grove of trees, Wilderness Park is not visible from the road or any parking lots, and requires walking a fair distance from parking. The noise from traffic and crowds is negligible, making it an ideal location for those seeking solitude, relaxation, or wildlife viewing. Wilderness Park responses reflected this situation, with relational values ranking highest and the most common reason for visiting being wildlife viewing/exploring nature. These findings support our hypothesis that the most common reasons for visiting reflect the SES value expressed at that waterscape.

Values often reflected reason for visiting waterscapes, although the frequency of reasons given was not always reflective of typical activities at each site. For example, Rio Vista sees thousands of tubers pass through the park every year, but only a handful of people indicated they were visiting for tubing. However, the prominence of utilitarian values at Rio Vista should be considered, especially since utilitarian values were so rarely cited across the entire study area. Rio Vista is catered toward recreation activities such as kayaking and tubing down the river rapids. This result may imply that value orientations are dependent on visual or social waterscape features, and values vary more according to setting than individual experience or perceptions. While aspects of social demand for blue spaces did not vary significantly among SMR sites, the range of responses reflects the myriad of activities and diversity of experiences that take place in these waterscapes every day.

4.2. Quantifying Emotional Experiences as a Measure of Restorative Potential of Waterscapes

The findings described in the previous section support the idea that emotional experiences are mediated through the symbolic meaning of place [9,17]. Those that demonstrated an intrinsic or relational value may feel a deeper sense of connection to blue spaces, which can increase the benefits to mental and physical health associated with exposure to blue spaces [6,58]. Logically, the reasons we perceive a place as important or valuable influence the ways those places affect us emotionally [9,71]. Thus, blue spaces impact our mood, and longitudinal exposure to blue spaces can result in positive outcomes for community health [15]. Positive emotions were experienced at waterscapes significantly more often and to a higher degree than negative emotions, reflecting the potential for waterscapes to provide community health benefits and restoration from stress [6].

Quantifying emotions can bring to light what seems obvious; the San Marcos River SES is a source of pleasure, education, and enlightenment for community members and visitors alike. Momentary affect may help reveal implications for community wellbeing [6]. Rather than a purely quantitative approach, the framework of this study was targeted toward community engagement and communication of stakeholder perspectives; thus, a mixed-methods analysis was needed to capture holistic relationships with urban waterscapes [46,72]. These data help water managers identify areas of need, i.e., where maintenance, environmental monitoring, or increased enforcement of regulations would be beneficial.

Ranked correlations revealed that lower perceptions of flow, cleanliness, and naturalness resulted in a lower intensity of positive emotions (joy, serenity, and amazement). These results provide evidence that experiences of urban waterscapes likely depend on the biophysical aspects of those waterscapes. While the statistical analysis did not support our hypothesis that waterscape perceptions would significantly predict negative emotions, it did reveal that waterscape perceptions, especially biophysical perceptions, influence positive emotional experiences. This shows that it is not aesthetics alone, but perceptions of SES function that mediate experiences with waterscapes. Less positive emotional experiences at the intermittent tributary site support conclusions from Cottet et al. [73] that intermittent streams are often devalued due to stakeholder perceptions and lack of meaningful interaction with these streams.

The concept of *nature* is complex and contested [74]. The San Marcos River, like most urban waterways, is an altered and intensively managed ecosystem that is problematic to claim as natural. Rather than assigning the label of natural to any of the waterscapes, we based our analyses on perceptions of naturalness—using ranked values to look for associations between perceptions and behaviors. This allowed participants to define natural for themselves and reflect on how they assign that attribute to an urban landscape. Different people will have different ideas of what naturalness is, and some participants commented on this, with one stating the following: "Natural seems like a problematic adjective. I feel like it's a beautiful place either way but there's clearly anthropogenic influences, like there are in any landscape in one way or another."

Interactions with blue spaces can produce happiness, relaxation, and reflection, and they contribute to physical and mental wellbeing in the long term [12,15,58,69,75]. Blue spaces can also provide opportunities for social interaction, education, and restoration [15,17,76], which can promote positive health outcomes and foster a sense of place that promotes waterscape stewardship [7]. San Marcos, Texas is a community that protects and cherishes its river, and the positive emotions experienced across sites reflect this culture of stewardship [7,8].

4.3. Using Relational Values to Examine Interactions and Perceptions of Waterscapes

Relational values move beyond traditional ecosystem services to represent relationships with and responsibility to place [42]. Measuring relational values of waterscapes allows water managers to view nature–human relationships through expressions of SES values and meanings [7]. As part of social–ecological systems (SES), humans change and are changed by their place attachments. In our study, intrinsic and relational values were balanced but much more common than utilitarian values. Those representing a relational value had more positive emotional experiences than those with a utilitarian value and had the highest perception of waterscapes as a "refuge".

Relational values aim to represent the complex and dynamic ways that people can relate to and feel about nature [14,38]. The mental health benefits provided by blue spaces are mediated and negotiated through our experiences, perceptions, and beliefs [31,58]. Therefore, relationships may represent symbolic meaning of place, and that meaning can change or be reinforced through new experiences [6]. Qualitative analysis of comments left by participants revealed the dynamic ways in which characteristics of blue spaces can negotiate emotional reactions, perceptions, and relationships with place. Relational values were expressed as nuanced relationships with waterscapes that represent responsibilities and attachments to these places, as well as personal emotional experience, such as "nostalgia" expressed by many in the comments (Table 9).

The different meanings of place and the complexity of factors that Influence that meaning are partly captured through a survey of relational values; however, to understand what relational values represent to different people, qualitative analysis is crucial. A cost–benefit analysis of ecosystem services in the traditional empirical sense would fail to account for these types of relationships and experiences [47]. For many people, buy in for supporting ecosystems increases when they are coproducers of knowledge [22]. Managers face tradeoffs when planning urban blue and green spaces and may benefit from a relational values approach. By using a participatory approach such as ours, policy can reflect human experiences with blue spaces rather than just a quantification of the monetary or anthropocentric benefits they provide.

4.4. Emerging Effects of COVID-19 on Nature–Human Interactions

In line with previous literature, we found that 90% of participants perceived waterscapes as a refuge from the stress and isolation caused by the COVID-19 pandemic. About half of participants reported spending more time at urban waterscapes than they did before the pandemic, while the other half indicated spending less time or the same amount of time. These results reflect the complex conditions of the pandemic that has simultaneously made people more isolated and more curious about exploring nature [57].

The pandemic increased feelings of negativity, stress, grief, and economic loss [77,78]. Medical research has called for interventions that offer preventative care to reduce the potential for negative mental health symptoms amplified by the pandemic [79]. Collective stressful events can provide opportunities for landscapes and waterscapes to act in a transformative way. Connectedness to nature can lead to mobilization that promotes collective action [80] and may lead communities to hold refuge opportunities in higher regard [58]. The framework presented in this study is also a starting point for designing new landscape monitoring or environmental education programs that foster connections with nature while maintaining social distancing and other COVID-19-related safety measures. The data collection period for this study took place from May 2021 to March 2022. At this time, city parks had been reopened for 8 months after they had been closed from March to September 2020. While our results do not reflect relationships with urban waterscapes during lockdown, they show how waterscapes were a refuge in a time of great uncertainty and isolation.

4.5. Qualitative Analysis of Photos and Comments

In San Marcos, there is a cultural and social norm of reverence and protection for Spring Lake and the San Marcos River [7]. During our time installing or replacing stations at various sites, we had conversations with community members that possessed extensive knowledge of the ecological conditions and wildlife of the San Marcos River, including endangered species and the history of protection that partly stems from their presence. Over 300 people left additional comments expanding on their answers or providing unsolicited information.

From text mining the additional comments, we found many of the same keywords used across the sites (Table 9). For example, many participants wrote "clear" in additional comments, and commented on how optical water quality was a draw to the river, lake, or wetland. The wetland was unique, however, in that it was the only site where "wildlife" was mentioned in the top five keywords. It is likely that some respondents observed wildlife in this rich habitat, but there was also the perception of wildlife because this site was considered the most "natural" among the different waterscapes (Figure 4). It is also likely that the educational signage along the wetland boardwalk gave the perception of wildlife. The third most mentioned word at the intermittent tributary was "stagnant" (Table 9), reinforcing the finding that perceptions and beliefs mediate personal experiences with waterscapes [7–9].

Qualitative analyses of comments also reflected respondents' environmental concerns for the integrity of the river. Negative comments were often accompanied by a concern for perceived misuse or degradation of the river ecosystem. Ten comments mentioned trash or pollution of the river. One participant remarked the following: "Green algae from fertilizer must be stopped. City ordinance to prohibit its use is the only way. Trash in the bends of river is gross. Must fine offenders through camera evidence". This concern for the river may not have been captured in a purely quantitative analysis of social demand.

Many comments showed a deep knowledge of the ecosystem composition, history, and functions of the San Marcos River. On several occasions, species were identified correctly by name. People commented on the coverage and health of the Texas wild rice (*Zizania texana*; Figure 7) over time, and it was the third most mentioned word at the perennial river site. One participant pointed out the ways the pandemic and lack of visitors to the river had been helpful in restoring wild rice populations. Participants also expressed appreciation for the symbolic or environmental significance of the ecosystem. As one participant phrased it, the river has "a certain magic . . . it's spiritual".

Figure 7. Texas wild rice (*Zizania texana*) in Sewell Park (Site #6). Photo by M. Wade.

Many people in San Marcos have pursued or been exposed to environmental education about the river system. The Meadows Center for Water and the Environment located next to Spring Lake is committed to educating people about the ecosystems and history of the spring-fed lake and river system. Knowledge about specific ecosystem functions or species may create a heightened sense of responsibility to monitor and protect those things [8]. One participant even stated this directly: "Having waterscapes like this in my community makes me more invested in maintaining their health and conserving their ecosystems". See Appendix B for all comments.

In addition to documenting nature–human relationships as functions of SES values and perceptions, this project resulted in a temporal and spatial database of participant-submitted photos. Photos taken from the same angle of the same place over a 10 month period provide visual data of landscape variability and change over time. Time-stamped photo databases provide insight into the ways that extreme weather events or land-use practices including recreation affect San Marcos waterscapes. On one occasion in October 2021, the San Marcos River experienced a major flood and became quite turbid. Participants submitted photos in the aftermath of the storm that may help reveal the timing and duration of hydrologic responses to extreme flood events (Figure 8).

Figure 8. Receding floodwaters on 18 October 2021 at City Park (Site #3). Photo by anonymous respondent.

Photo submissions documenting changes and extreme events promote this collective value [54,55]. Providing photos and their experiences and emotions allows stakeholders to take ownership of their role in the production of knowledge and the protection of the ecosystem [22,23,80]. The mixed-methods approach allowed for nuanced experiences to be incorporated with quantitative data analysis to provide holistic representations of relationships with place. Without the qualitative approach, these perspectives would not have been considered.

4.6. Limitations to Study

There was an inherently spatial limitation to this study that created a selection bias. Only those that are physically visiting the river and willing to engage with a cell phone application were participants in the study. Therefore, this analysis missed an opportunity to assess perceptions in populations that have limited access to blue spaces or technology. The locations of our photo stations may have also created a spatial bias. The site at Rio Vista Island, for example, was not prominent along a heavily trafficked trail and, thus, had a very small sample size (n = 12). As with all survey data, these data were subject to errors from humans either rushing through the assessment or giving intentional false information.

Another limitation of the assessment was the question asking if people spent more or less time at waterscapes than they did before the beginning of the pandemic. City parks were closed due to COVID-19 for over 6 months prior to the beginning of the assessment period, which could have led to confusion about what the question meant by "since before the pandemic". This wording may also have been confusing for those who moved to the area during the pandemic. Emotional variables likely faced ceiling effects, as a majority of people ranked positive emotions 4 or 5 out of 5. A more effective method may be to ask about specific emotional reactions to place and rank these emotions, rather than placing them on an intensity Likert scale.

5. Conclusions

The benefits of blue spaces are influenced by visual biophysical characteristics but are also shaped by unseen emotional experiences. In sum, blue spaces (or waterscapes) have profound and measurable benefits to overall wellbeing, especially in urban settings where stressors are typically more intense and ubiquitous. Maintaining healthy blue spaces is a cost-effective way to mitigate negative mental health effects from these stressors. In central Texas, unique blue spaces are held in high regard and are seen as a symbol of the cultural, social, and environmental history of the region. The community of San Marcos, including resources managers, is faced with determining the future of their waterscapes in terms of access versus protection. Community surveys such as ours can ensure that different perspectives are considered in assessments of potential tradeoffs in water resource management.

Understanding and considering diverse stakeholder perspectives is essential to the sustainable management of blue spaces. In this regard, relational values are an emerging framework to appreciate the interdependent relationships between people and nature as part of a social–ecological system (SES). Our results show that people in San Marcos, Texas (USA) uphold waterscapes mostly for their intrinsic and relational values, more so than utilitarian values. Waterscapes produced positive emotional experiences, which were dependent on perceptions of flow, cleanliness, and naturalness. Waterscapes were perceived as a refuge from stress in general, and from the stress caused by the COVID-19 pandemic.

Documenting photos and relationships with waterscapes, as we did with this project, provides insight into relevant waterscape changes and SES values. Future research could use geotagged photos as a qualitative expression of cultural relationships with place and to track changes to waterscapes over time.

Planning green and blue spaces in urban settings often comes with difficult tradeoffs and can be influenced by push–pull factors from competing or contrasting interests within the community. By collecting perspectives from stakeholders that go unseen and unheard, this project promotes the equitable consideration of stakeholder interests when considering tradeoffs between community interests in blue space management.

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

Appendix A. Waterscape Site Descriptions [All Photos from Anonymous Respondents]

City Park (#2)

City Park is one of the more popular river access points for community members and tourists. City Park is connected to two parking lots on either side of the river and has access points on both sides (Figure A1). Typical of San Marcos parks, river access points are lined with large concrete blocks on the west side. The other side is paved and has steps leading from the parking lot to the river. The east side of the park features the Lions Club Tube Rental facility, where tens of thousands of people rent tubes each year to begin their float down the river. While City Park is a popular tubing hub, the most common reason for visiting cited by participants was family event/date/socializing, which reflects the fact that City Park is a frequent destination of families or friends for picnics, birthday parties, or swimming at the river. The most common value expressed was relational. This reflects the fact that City Park is designed and maintained through human alterations to facilitate access to and interaction with the river.

Figure A1. View from Blue Index station #2: City Park.

City Park on Bridge (#3)

Station 3 was attached to an existing bridge that connects sidewalks on either side of City Park (Figure A2). While located just downstream of the river access points at City Park, the view and types of activities seen on or from the bridge are slightly different, as there are fewer river access points in view. The bridge connects the larger greenbelt system that connects city parks along the stretch of the San Marcos. The most common value expressed at City Park Bridge was relational. The most cited reason for visiting was family outing/date/socializing.

Figure A2. View from Blue Index station #3: City Park on Bridge.

Rio Vista Park (#4 and #5)

Located about half a mile downstream from City Park, Rio Vista Park is a popular endpoint for most tubing activities, and it features the rapids that draw thousands of tubers each year. Two study sites were installed at Rio Vista Park at varying levels of accessibility and different stretches (Figures A3 and A4). Station #4 was installed on an existing post on Rio Vista Island, an island that sits in the middle of the river as it meanders around toward the rapids. The most common value stated here was relational, and the most common reason for visiting was work/school as one small group of students attended the Blue Index photo station as part of an assignment for class. This station had the lowest response rate.

Station #5 was installed on a T-post near the rapids. The sign faced Ivar's River Pub, a restaurant directly on the bank of the SMR. This is one of the busiest areas for recreation activities along the river. The site is unique because it is the only site that features a view of a building directly adjacent to the riverbank. Historically, development has not taken place along the banks of the San Marcos, but Ivar's River Pub, which has existed at the park since 1996, sets a precedent for riverbank development along the SMR. The most expressed value at site #5 was utilitarian, the only site in which this value ranked first. This value orientation reflects the typical activity of the river, as Rio Vista is a major destination for tourists and community members for outdoor recreation and water sports. The most cited reason for visiting at site #5 was work/school, as a group of students visited the site as part of a class assignment. The second most cited reason for visiting was exercising.

Figure A3. View from Blue Index station #4: Rio Vista Island.

Sewell Park (#6)

Sewell Park is located on Texas State University campus and is a popular destination for education and leisure for Texas State University students and staff (Figure A5). A typical afternoon at Sewell sees hundreds of students sunbathing, swimming, tubing, and kayaking along the river. While the park is specifically designated for students and staff of the University, hundreds of tourists and community members visit Sewell Park to swim or begin their water sports activities. Most participants at this site were students in the 18–24 age range. Student participants reported frequent use of the SMR at Sewell Park, with over half of the participants visiting the park weekly or monthly. The banks of the SMR at Sewell Park are paved, and the park represents an intersection of natural and designed systems. As one participant put it, "half of it is for nature and the other half is available for humans to use for recreational purposes". This mixed-use space produced results that showed a preference for the relational values experienced at the park. The most cited use was relaxing/stress relief/meditating.

Figure A4. View from Blue Index station #5: Rio Vista Park.

Figure A5. View from Blue Index station #6: Sewell Park.

Ramon Lucio Park (#7)

Ramon Lucio Park is located adjacent to I-35 and is the last park on the San Marcos River stretch on the West side of I-35. The park features several river access points lined with concrete blocks. The photo station was installed on an existing bridge over the river at the park, facing I-35 (Figure A6). This park is frequented by groups of friends playing music, having picnics, or swimming. River entrance points are less accessible than City Park. Ramon Lucio Park is located at a turn in the river and is up to 10 feet deep in some areas. The most expressed value at this site was relational. The most cited use was wildlife viewing/exploring nature, but relaxing/stress relief/meditation was the second most cited use.

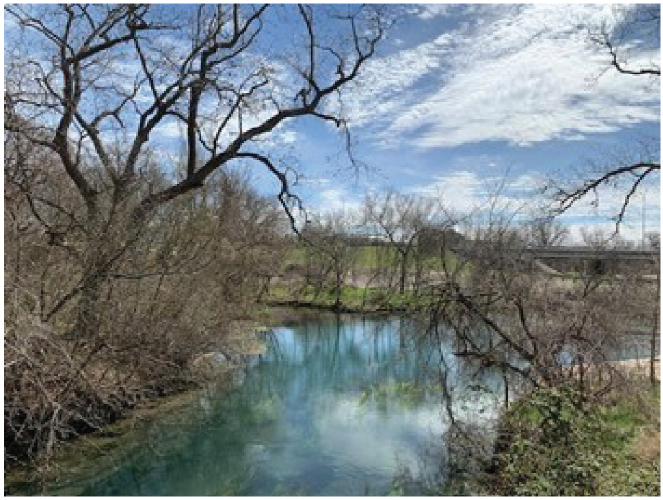

Figure A6. View from Blue Index station #7: Ramon Lucio Park.

Wilderness Park (#8)

Wilderness Park, also known as Crook Park and sometimes referred to as Girl Scout Park, is located between Rio Vista Park and Ramon Lucio Park (Figure A7). Wilderness Park has several river access points, but no part of the park or riverbank is paved. The most commonly expressed value at Wilderness Park was relational, meaning the opportunity for connection was held in the highest regard. The most cited use from results at this site was wildlife viewing/exploring nature.

Figure A7. View from Blue Index station #8: Wilderness Park.

Spring Lake near Meadows Center (#9)

Spring Lake is spring-fed from the Edwards Aquifer and forms the headwaters of the San Marcos River. Station #9 is located at Spring Lake near the Meadows Center with a view of the glass-bottom boats (Figure A8). Spring Lake is not accessible to swimmers or water recreators but is explorable via a tour of the lake on a glass-bottom boat. The most expressed value at this site was intrinsic, and the most common use was work/school, followed closely by wildlife viewing/exploring nature.

Figure A8. View from Blue Index station #9: Spring Lake near Meadows Center.

Meadows Center Wetland Boardwalk (#10)

Station #10 was installed on existing rails along the Meadows Center Wetlands Boardwalk (Figure A9). The boardwalk is maintained and managed by the Meadows Center, and there are several informational stations along the boardwalk that provide facts about the wetland ecosystem, endangered species, and non-native species that live in the wetland. The wetlands at Spring Lake are adjacent to Aquarena Springs, a busy street that connects Texas State University campus to the larger San Marcos area. The most cited SES value at this site was intrinsic, and the most frequent use was wildlife viewing/exploring nature.

Purgatory Creek at Bicentennial Park (#11)

Station #11 was attached to an existing bridge that crosses Purgatory Creek, an intermittent tributary of the San Marcos River that is usually stagnant because of the backwater effect from the mainstem river. The bridge is located at Bicentennial Park, a frequent destination for walkers, bikers, swimmers, and tubers. The photo station featured an upstream view of Purgatory Creek, which has unpaved banks and is lined by trees on either side (Figure A10). The most expressed ecosystem value at this site was intrinsic, and the most common uses were exercising and relaxing/stress relief/meditation.

Figure A9. View from Blue Index station #10: Meadows Center Wetland Boardwalk.

Figure A10. View from Blue Index station #11: Purgatory Creek at Bicentennial Park.

Appendix B. Blue Index Assessment

1. By selecting "I Acknowledge" below, you acknowledge that "I grant permission to the researchers for the use of my uploaded waterscape photograph in any presentation or product of this research. I understand that I am entering a Creative Commons Attributions Noncommercial No Derivatives license. My photo will not be changed or sold. It will be used to share knowledge of San Marcos waterscapes with the public and park managers."

2. Take a photo of the waterscape in front of you if you have not already. Upload your photo of the waterscape from your photo storage folder.

3. Take 10–20 s to observe the waterscape in front of you. Which feeling(s) best describe your experience? Drag your finger on the sliders to rate the intensity of what you are feeling. A higher rating means more intense emotion. You must touch each slider even if your response is 0 (no emotion). joy; serenity; disgust; fear; sadness; amazement; other (blank text box).

4. Compared to my usual sources of relaxation, this waterscape is: (Likert scale) considerably less relaxing; somewhat less relaxing; neither less or more relaxing; somewhat more relaxing; considerably more relaxing.

5. How much do you agree or disagree with the following statements: (Likert scale) completely disagree; somewhat disagree; neutral; somewhat agree; completely agree. This waterscape has flowing water; this waterscape was easily accessible; this waterscape is clean enough to touch or swim in; this waterscape represents a natural environment; this waterscape is a refuge from stress.

6. Optional: Please use this space to describe what stands out most to you about this waterscape or elaborate on any of your above responses: open text response box; 500 characters max.

7. I came to this waterscape for: (mark all that apply) community event/music event/special occasion; commuting; dog walking; exercising; family outing/date/socializing; fishing; art/photography; relaxing/stress relief/meditating; solitude; water sport/tubing; wildlife viewing/exploring nature; work/school; prefer not to answer.

8. This waterscape is most important because: (choose one) it provides ecosystem functions such as wildlife habitat (intrinsic value); it provides useful benefits to society such as recreation and tourism (utilitarian value); it provides an opportunity for the community to connect with a natural environment (relational value).

9. Thinking back to before the beginning of the pandemic in March 2020, do you spend more or less time around waterscapes like this one now? (Likert scale): considerably less time; somewhat less time; neither less or more time; somewhat more time; considerably more time.

10. To what extent would you agree with the following statement: "Spending time around waterscapes like this one helps me cope with the isolation or stress of the pandemic"? (Likert scale): completely disagree; somewhat disagree; neutral; somewhat agree; completely agree.

11. My permanent zip code is: open text response box.

12. Are you currently a resident of San Marcos or do you reside in San Marcos for the majority of the year? Options: yes; no.

13. What is your age range? Options: less than 18 years (these responses were deleted); 18 to 24 years; 25 to 34 years; 35 to 44 years; 45 to 54 years; 55 to 64 years; 65+ years.

14. How do you describe yourself? (Check one): female; male; nonbinary; prefer not to answer.

15. Please indicate your level of education. (Check one): less than high school; high-school graduate; some college (currently in college at Texas State University); some college (currently in college at another institution); some college (not currently enrolled); 2 year degree; 4 year degree; master's/professional degree; doctorate.

16. I traveled to this waterscape by: (mark all that apply) foot; bike; car; bus; train; boat; plane; other; prefer not to answer.

17. Is this your first time visiting this waterscape? Options: yes; no.

18a. (If yes on 17) How often do you come to this waterscape? Options: daily; weekly; monthly; a few times a year or less.

18b. (If no on 17) Would you return to this waterscape? Options: yes; no.

Appendix C. Participant Demographics and Waterscape Site Descriptions

Table A1. Demographic characteristics of participants across all sites. Photo station numbers (in parentheses) can be located in Figure 1.

	All Water-scapes	City Park (#2)	City Park Bridge (#3)	Rio Vista Island (#4)	Rio Vista Park (#5)	Sewell Park (#6)	Ramon Lucio Park (#7)	Wilderness Park (#8)	Spring Lake (#9)	Wetlands at Spring Lake (#10)	Purgatory Creek (#11)
Age (all units % of total responses at each site)											
18 to 24 years	51.3	70.0	55.6	72.7	81.0	62.4	41.2	65.4	44.6	39.0	38.2
25 to 34 years	20.5	6.7	24.4	18.2	9.5	21.2	27.5	15.4	24.3	20.7	19.1
35 to 44 years	13.4	13.3	2.2	9.1	9.5	7.1	11.8	7.7	17.6	24.4	16.2
45 to 54 years	10.1	6.7	15.6	0	0	9.4	9.8	11.5	8.1	14.6	10.3
55 to 64 years	3.2	3.3	2.2	0	0	0	7.8	0	2.7	1.2	10.3
65+ years	1.4	0	0	0	0	0	2.0	0	2.7	0	5.9
Education (all units % of total responses)											
Less than high school	0.2	0	0	0	0	0	2.0	0	0	0	0
High-school graduate	3.7	3.3	6.8	0	4.8	0	5.9	0	0	2.4	11.8
Some college—Texas State student	37.6	50.0	43.2	72.7	66.7	49.4	27.5	46.2	33.8	26.8	20.6
Some college—other institution	4.7	0	2.3	0	4.8	2.4	3.9	3.8	10.8	4.9	5.9
Some college—not currently enrolled	4.5	0	6.8	0	4.8	1.2	3.9	11.5	5.4	4.9	5.9
2 year degree	3.5	0	4.5	0	4.8	2.4	3.9	3.8	2.7	6.1	2.9
4 year degree	23.6	10.0	15.9	18.2	14.3	20	27.5	23.1	21.6	35.4	27.9
Master's/professional degree	17.9	33.3	15.9	9.1	0	0	19.6	11.5	17.6	17.1	19.1
Doctorate	4.5	3.3	4.5	0	0	0	5.9	0	8.1	2.4	5.9
Gender of Participants (all units % of total responses)											
Female	64	66.7	68.9	63.6	71.4	60.2	60.8	61.5	59.4	71.2	59.7
Male	33.1	30	26.7	36.4	28.6	32.5	35.3	38.5	37.8	26.2	38.8
Nonbinary	2.9	3.3	2.2	0	0	7.23	7.2	0	2.7	2.5	1.5
Residency Status (all units % of total responses)											
Self-described resident	63.2	70	62.2	81.8	81	71.8	60.8	65.3	54.1	56.6	60.3
Self-described nonresident	36.8	30	37.8	18.2	19	28.2	39.2	34.6	49.9	43.4	39.7
78666 permanent zip code	42.7	55.6	42.9	30	38.1	47	46.7	42.3	32.4	39.5	47.6
Other permanent zip code	57.3	44.4	57.1	70	61.9	53	53.3	57.7	67.6	60.5	52.4
Frequency of Visit (all units % of total responses)											
Daily	6.4	8.3	3.2	0	0	3.9	18.8	0	5.3	6.5	9.8
Weekly	28.8	37.5	29	0	17.6	38.2	25	53.3	10.5	15.2	41.5
Monthly	24.5	33.3	38.1	57.1	29.4	27.6	21.9	26.7	10.5	13.0	22.0
A few times a year or less	40.4	20.8	29	42.9	52.9	30.3	34.4	20	73.7	65.2	26.8

Appendix D. Additional Comments

Table A2. Additional comments left by participants during the assessment.

Comment	Site
After coming back from Houston for winter break, this is the perfect spot to relax and unwind.	City Park (#2)
All the different plants and trees along the water.	City Park (#2)
Calm.	City Park (#2)
Clear, some wild rice. Considerably less due to recreation.	City Park (#2)
Fun, exciting, a place to hang out with friends.	City Park (#2)
Great station location! Nice water entry points here.	City Park (#2)
I came to the river to destress after my run. The river calms me down and allows me to take a deep breath and obtain the much needed break from school, work, and negative things going on in my life. I love how nature can have an extreme impact on our mood.	City Park (#2)
I love how accessible it is. It's a nice place to be connected to nature and other people.	City Park (#2)
I love how blocked off this area is from the road. You can still hear road noise, but I feel like I'm tucked away in a little escape. And even the built environment around this section of the river looks really nice.	City Park (#2)
I swim here at down at least 3 days a week. I am disabled and use the metal stairs. During sights and sounds, the city removes my access and forces me to use the more dangerous and difficult stone stairs on the other bank. In the water, I am part nature.	
It represents gratitude for the gem that it is for its beauty, community connector, and healing source for humans for over 14,000 years, not to mention all its wildlife with the same properties. Thank you for all is done for conservation & preservation of this amazing natural resource! Grateful SMTX Resident	City Park (#2)
People kayaking.	City Park (#2)
The lush green scenery really stands out to me, plus the calm look of the river.	City Park (#2)
The river is beautiful and a space I come to relax at. The swimmers are a bit loud, making it slightly unpleasant. The water is very clean.	City Park (#2)
the traffic here in all aspects is significantly less than the last location.	City Park (#2)
The water in this area is more calm and very clear.	City Park (#2)
The wild rice stand population and trees on the bank stand out the most to me about this waterscape.	City Park (#2)
This part of the river has plenty of space and is much quieter and relaxing.	City Park (#2)
This waterscape is more quiet in comparison to Sewell Park. There is much less noise here.	City Park (#2)
Water clarity.	City Park (#2)
What stands out to me most about this waterscape is the broadness of it. Just upstream at the previous waterscape, the river seems more narrow and windy. This waterscape resembles a pool to me.	City Park (#2)
Beautiful to see families and groups of friends from many backgrounds enjoying the river. Accessibility is important for all. Keeping Texas rivers clean is so important.	City Park on Bridge (#3)
Calm, quiet, a bit of trash.	City Park on Bridge (#3)
Clear water, safe space for people and animals.	City Park on Bridge (#3)
Endangered wild rice growing.	City Park on Bridge (#3)
I like that the riparian environment is being repaired and replanted, it's nice to see new plants and wildflowers growing in the area.	City Park on Bridge (#3)
I loved watching the sea grass wave like hair in the water.	City Park on Bridge (#3)
I've never seen it this murky I'm scared to float in it, I assume it's because of the recent rain.	City Park on Bridge (#3)
It's a beautiful place to see the beauty of nature and human architecture together with the bridge you can see. It may not be as swimmable with the reeds in the water, but it's a beautiful place to see the natural habitats of the river and animal life like the turtles.	City Park on Bridge (#3)
Large source of water is easily visible.	City Park on Bridge (#3)
My family and I enjoyed the visit to the beautiful landscape.	City Park on Bridge (#3)
Nowhere to get in.	City Park on Bridge (#3)
Peaceful reprieve in the city.	City Park on Bridge (#3)
Seems to be more natural than other spots on this river.	City Park on Bridge (#3)

Table A2. *Cont.*

Comment	Site
Someone built this place thoughtfully so that others may heal. Too bad the shadows of hatred, violence, loneliness, and pain echo throughout the surrounding region.	City Park on Bridge (#3)
The clarity of the water is peaceful to look at. I think there would be more fear if the water was murky. I did not feel fear.	City Park on Bridge (#3)
The clarity of water and lack of pollution from an intrusive gas pipeline or other intrusive things.	City Park on Bridge (#3)
The clear waters are very pretty, I can even see fish in the water. And I kind of really like the style of bridge that you can see in the distance. It's kind of industrial which is really pretty paired with the natural environment.	City Park on Bridge (#3)
The Texas wild rice is always captivating, relaxing, and mesmerizing to me. My favorite time to come here is in the fall or winter when there are less people in the water which causes the water and sediment to be less disturbed.	City Park on Bridge (#3)
The vegetation is very visible and appears to be healthy.	City Park on Bridge (#3)
This is my favorite view of the river, the long strands of wild rice flowing with the river is so calming to watch.	City Park on Bridge (#3)
Trees.	City Park on Bridge (#3)
We find the waters of the SM river to have a certain magic to them—the history, the color, the constant temp—it's spiritual.	City Park on Bridge (#3)
What stand out most to me about this watershed is the plants in the water.	City Park on Bridge (#3)
You can't access the water from this specific part of the bridge.	City Park Bridge (#3)
I feel the water color has been impacted by ongoing construction and winter time.	Upper Rio Vista Island (#4)
A lot of human activity right by the river, dam presence, manmade and natural canal construction.	Rio Vista Park (#5)
Good.	Rio Vista Park (#5)
I felt a bit of sadness because I used to come to this park during a rough time in my life, but it is still beautiful.	Rio Vista Park (#5)
I saw a large duck swimming in the water.	Rio Vista Park (#5)
The Cyprus tread and the blue/green flowing water create a unique and beautiful landscape that elicits feelings of both fun and peace.	Rio Vista Park (#5)
the little ecosystems around the area stand out the most. although hundreds of people swim in this river they're still thriving.	Rio Vista Park (#5)
The river shoot that is toward the end of the stream.	Rio Vista Park (#5)
This part of the river is definitely more populated and noisy.	Rio Vista Park (#5)
This point of the river is currently being used for various recreation activities—tubing, paddle boarding, swimming, and hanging out. It is surprisingly quiet, despite about 20 people at the park. There is quite a bit of construction going on, along with fencing around the river, which concerns me. I know this park gets incredibly busy on weekends with good weather and there is a restaurant across the river that draws in even more. It is also the final stretch of a commercial tubing operation.	Rio Vista Park (#5)
As a San Marcos River Ranger, it's an honor to serve.	Sewell Park (#6)
At beautiful as the water is, the construction, leaf blower/grade mowing, and car traffic sound caused the loss of the serenity completely.	Sewell Park (#6)
Beautiful wild rice and clear blue water.	Sewell Park (#6)
Besides the water, there are a lot of distractions, but focusing on the water is almost hypnotizing.	Sewell Park (#6)
Brown water from flood!	Sewell Park (#6)
Calm, less crowded than usual.	Sewell Park (#6)
Clarity, cleanliness, mystical.	Sewell Park (#6)
Clean, quiet, a way to connect with nature in the middle of a busy community.	Sewell Park (#6)
Clear beautiful water.	Sewell Park (#6)
Clear spring-fed water.	Sewell Park (#6)
I absolutely love this space, but I do believe there is a problem of trash that needs to be addressed. Tubers, swimmers, etc. visit and leave their trash and it sinks to the bottom. I've collected many pieces of glass that for those without shoes could seriously hurt them. There should also be more easily accessible stairs, either by adding a lower edge or ladder below the stairs. Even if the water is high, it takes a lot of effort to pull yourself up and out onto the stairs.	Sewell Park (#6)
I always feel rejuvenated after a swim in the San Marcos River.	Sewell Park (#6)
I like how half of it is for nature and the other half is available for humans to use for recreational purposes. It's a nice blend compared to other natural areas.	Sewell Park (#6)

Table A2. *Cont.*

Comment	Site
I love how the forced quarantine resulted in the river recovering so nicely. It's fun that people play in it but I also like the changes.	Sewell Park (#6)
It remains a very natural environment despite many people using it. It is a very alive river compared to many other commercialized areas. It's nice that there is part of the river for people to swim and also an area where water plants can thrive.	Sewell Park (#6)
Its openness.	Sewell Park (#6)
Lack of calmness or serenity comes from being on campus (rowdiness, stress, etc.).	Sewell Park (#6)
Love the water.	Sewell Park (#6)
Moderate activity and swimming happening at around 8 p.m. Clean surroundings.	Sewell Park (#6)
River rice.	Sewell Park (#6)
Recreation, wild rice, clear water.	Sewell Park (#6)
Road noise is overwhelming and mashed it tough to enjoy. Beautiful water though, even at night.	Sewell Park (#6)
Storm runoff. Atypical.	Sewell Park (#6)
The amazement of the waters' clarity stands out. It is mentally refreshing to see the pebbles at the bottom of the river and see the wild rice dancing in the water.	Sewell Park (#6)
The clarity of the water. I'm from the Waco area and the Brazos is very pretty but always muddy. There are obvious differences between this portion of the San Marcos River and the Brazos, but it's really nice to see water that's so clean and clear. The other thing that I can't help but notice is all the concrete. It makes everything accessible which is really nice but it's a little drab looking.	Sewell Park (#6)
The clear spring water makes Sewell Park a magical place to relax. The wild rice flowing in the current brings me peace and is a beautiful sight to behold.	Sewell Park (#6)
The clear water and recovering population of wild rice since before the pandemic.	Sewell Park (#6)
The clearness and the wild rice.	Sewell Park (#6)
The concrete banks stand out to me the most.	Sewell Park (#6)
The dedication to the naturalization of the area and preservation of endangered species is amazing and inspiring.	Sewell Park (#6)
The growth of vegetation in the river is definitely striking.	Sewell Park (#6)
The large amount of vegetation in the water. The clarity of the water is also extremely nice. It's a place where it feels clean to swim.	Sewell Park (#6)
The moving water.	Sewell Park (#6)
The park is busy but paying attention to the river puts me at ease.	Sewell Park (#6)
The road nearby created a lot of noise and distraction.	Sewell Park (#6)
The things that stand out most to me in this waterscape in front of me is the clearness of the water. Most water sources that I have surrounded myself with (usually throughout Texas) are murky and not as opaque as this river. It makes me feel very serene and calm as I look at the slow running that runs through it.	Sewell Park (#6)
The vast improvement in the native vegetation over the past decade.	Sewell Park (#6)
The waterscape captures the aquatic vegetation and urban landscape at the same time.	Sewell Park (#6)
The wild grass growth!	Sewell Park (#6)
There is vegetation growing in the river that looks healthy. The water is very clear and is obviously in a protected area.	Sewell Park (#6)
Today is concerning; it's very high, turbid, brown color, has a foam, and has a smell that's acidic.	Sewell Park (#6)
Water necessary for diverse/strong ecosystem with wild rice, different fish species, turtles, dragonflies.	Sewell Park (#6)
We love being so close to endangered species—I would love more information about them and what the scientists are doing to help! Parking was confusing, but the river environment is so incredible.	Sewell Park (#6)
Wild rice is looking healthy. Another algae cleanup would do it well. Tetras above bridge inspire research ideas and the hope of encountering a nice pair of sunglasses or a *Macrobrachium* is enough to justify a swim on any day.	Sewell Park (#6)
Despite a highway being right across the view, you don't really hear or notice. It's so calm and you feel a certain sense of clarity.	Ramon Lucio Park (#7)
A little oasis despite being so close to a busy highway.	Ramon Lucio Park (#7)
Beauty clear water.	Ramon Lucio Park (#7)
Clarity of the water.	Ramon Lucio Park (#7)

Table A2. *Cont.*

Comment	Site
Great use of our tax dollars! Ty! But could you turn off the noise from I-35? :-)	Ramon Lucio Park (#7)
Green algae from fertilizer must be stopped. City ordinance to prohibit its use is the only way. Trash in the bends of river is gross. Must fine offenders through camera evidence.	Ramon Lucio Park (#7)
Having waterscapes like this in my community makes me more invested in maintaining their health and conserving their ecosystems.	Ramon Lucio Park (#7)
How clear the water is and how it flows.	Ramon Lucio Park (#7)
How relaxing the place is compared to other parts of the water.	Ramon Lucio Park (#7)
I love how natural with the overgrowth of the banks this part of the river is but the sounds of I-35 make it less enjoyable.	Ramon Lucio Park (#7)
I saw a deer and a few ducks. It was cute.	Ramon Lucio Park (#7)
It was amazing and calming.	Ramon Lucio Park (#7)
It's a beautiful place. Although there's other people here, it's not too crowded, and they're playing good tunes, so that helps.	Ramon Lucio Park (#7)
It's fall and at 11 a.m. The water is very clear you can see down to the bottom.	Ramon Lucio Park (#7)
Live here just walking my dog after a few days of rain nice area to walk considering all other trails are muddy. No swimming today but it's usually clean.	Ramon Lucio Park (#7)
Lots of people uprooting the aquatic plants while swimming.	Ramon Lucio Park (#7)
Right off the bat there were peers of my age soaking up the sun and basking in the water. It stood out how clean the water was enough to enjoy.	Ramon Lucio Park (#7)
So blue.	Ramon Lucio Park (#7)
The blueish-green hue draws the eyes and envelopes me in a sense of serenity and closeness to nature as the soft-touch breeze invites me to observe the ripples on the surface and beckons me to sit on the bridge and stare undisturbed by the more material world around me. I feel not in a bustling city but in the vastness of the natural world.	Ramon Lucio Park (#7)
The bridge and the steps. Very calming.	Ramon Lucio Park (#7)
The bridge overlooking the water!	Ramon Lucio Park (#7)
The clarity of the water, and the number of people enjoying themselves with upbeat but not harsh music playing.	Ramon Lucio Park (#7)
The clear water.	Ramon Lucio Park (#7)
The cold river.	Ramon Lucio Park (#7)
The serenity and nature of this scene is very calming and a pleasant sight. It's easy to forget I-35 is so close and how busy the city is.	Ramon Lucio Park (#7)
The smell here is a little pungent. This is a busier area of the river and with more people comes more smells.	Ramon Lucio Park (#7)
The water after the rain.	Ramon Lucio Park (#7)
The water and scenery are amazing, but the amount of trash I consistently see is disheartening. So sad to see such a natural beauty disrespected.	Ramon Lucio Park (#7)
The water appears to be murky and unclear today and I'm wondering if it is from the construction at Rio Vista. :-(	Ramon Lucio Park (#7)
The water clarity is amazing.	Ramon Lucio Park (#7)
There is a highway in the background.	Ramon Lucio Park (#7)
There was a group of about 15 people hanging out and enjoying the river. Given that it's a Tuesday afternoon, I imagine that it's a regular thing. I prefer to hear the water, birds, etc., so no music, but at least their music wasn't terrible. There's a large concrete slab beneath the bridge and I don't really know what its purpose is, but it serves as an area for this group to hangout, although it detracts from the natural beauty of the river. There is also nearby construction noise.	Ramon Lucio Park (#7)
Water is more turbid than usual, but I am filling this out on a Sunday evening.	Ramon Lucio Park (#7)
Water is murky from rain, but the scene is peaceful and serene with birds chirping in the background. The only detractor is the noise from I-35 (nothing we can do about that).	Ramon Lucio Park (#7)
Water is very blue and clear. Bridge was very nice and vegetation as well. Really just a great little spot to chill at; nice and shady and relaxing.	Ramon Lucio Park (#7)
Besides the road noise, the calmness and silence in this area are very relaxing.	Wilderness Park (#8)
Clean and green.	Wilderness Park (#8)
Enjoying a beautiful morning at the clear, wonderful river.	Wilderness Park (#8)

Table A2. *Cont.*

Comment	Site
It's so clean and has beautiful colors and is so relaxing I love it.	Wilderness Park (#8)
San Marcos river is paradise.	Wilderness Park (#8)
Secluded and nice.	Wilderness Park (#8)
The clear water that seems to be clear of debris and waste.	Wilderness Park (#8)
The clearness of the water in the winter and the ease of access are a few of the things that draw me to this location.	Wilderness Park (#8)
The erosion on the embankment causing 5–7 trees to fall into the water over the last 4 years right here.	Wilderness Park (#8)
The water color is gorgeous. The light catches the water really beautifully. It feels like a little unknown pocket even though It's a public park. The shade is really nice and it's to see the underwater plants and rocks. Makes me want to jump in.	Wilderness Park (#8)
The water is clean and moving and easily accessible for a quick dip.	Wilderness Park (#8)
There are lots of small pieces of trash which makes me sad. I wish people cared more to take care of this beautiful waterway which brings so much joy and recreation opportunity to students and those alike.	Wilderness Park (#8)
This part of the river feels more quiet and secluded, which is nice. Sometimes it's hard to find a good spot on the river that's not too busy.	Wilderness Park (#8)
This waterscape is much more serene than the one before (#7). While there's still a bit of noise from construction and traffic, it's muffled off in the distance. You can hear the wind rustling the leaves and birds chirping. It was slightly less accessible than #7, but still very accessible in my book with less than 5 min walk from the car. There are people enjoying this waterscape as well, but in smaller, quieter groups of 1–2.	Wilderness Park (#8)
Traffic noise is only thing bringing lower rating.	Wilderness Park (#8)
Water current.	Wilderness Park (#8)
Water was very blue, much more than I expected. Also, park was a bit hard to get to because of construction near Sewell. * * This participant was likely referring to construction at Rio Vista Park.	Wilderness Park (#8)
Clear water and reflection of the sun. A lot of vegetation and creatures.	Spring Lake near Meadows Discovery Center (#9)
Amazement at the spring-fed lake and its incredible beauty and all the fascinating creatures that live in the lake.	Spring Lake near Meadows Discovery Center (#9)
Beautiful origin of the start of the river.	Spring Lake near Meadows Discovery Center (#9)
Calming way to start the day. Meditative.	Spring Lake near Meadows Discovery Center (#9)
Clear water.	Spring Lake near Meadows Discovery Center (#9)
Horizon scenery.	Spring Lake near Meadows Discovery Center (#9)
How clean the water is you can see fish at the bottom on the banks.	Spring Lake near Meadows Discovery Center (#9)
How clear the water is, very nice to see all that is in the water.	Spring Lake near Meadows Discovery Center (#9)
I love how you can see the algae/vegetation. It's clear enough to also see the fish and turtles in the water. I love the type of sand they use for this waterscape! I wish it didn't have a fence around it but I understand it's for the environment! I was curious though because I saw an employee throw something inside the water.	Spring Lake near Meadows Discovery Center (#9)
It feels very relaxing and idyllic. "Natural" seems like a problematic adjective, I feel like it's a beautiful place either way but there are clearly anthropogenic influences, like there are in any landscape in one way or another, I especially liked seeing the Nuphar plants.	Spring Lake near Meadows Discovery Center (#9)
It's an amazing natural water space with lots of opportunity to see wildlife, but it is not easily accessible because of university parking.	Spring Lake near Meadows Discovery Center (#9)
Listening to all the birds and insects around the headwaters and the occasional jumping fish. This place is good for my soul.	Spring Lake near Meadows Discovery Center (#9)
Quite different from the surrounding water areas. It's standing and gross.	Spring Lake near Meadows Discovery Center (#9)
Serenity.	Spring Lake near Meadows Discovery Center (#9)

Table A2. *Cont.*

Comment	Site
Spring Lake is absolutely gorgeous. I am so grateful this resource is available to the public.	Spring Lake near Meadows Discovery Center (#9)
The beautiful skyline and serene calm water.	Spring Lake near Meadows Discovery Center (#9)
The calm water stands out the most to me. And the boats!	Spring Lake near Meadows Discovery Center (#9)
The clear spring waters, the protected wetlands, the plants and animals.	Spring Lake near Meadows Discovery Center (#9)
The clear water.	Spring Lake near Meadows Discovery Center (#9)
The clear water and greenery below.	Spring Lake near Meadows Discovery Center (#9)
The clearness of the river and the high possibility of seeing wildlife.	Spring Lake near Meadows Discovery Center (#9)
The glass bottom boats stand out most to me.	Spring Lake near Meadows Discovery Center (#9)
The lake.	Spring Lake near Meadows Discovery Center (#9)
The super clear blue water.	Spring Lake near Meadows Discovery Center (#9)
The water is blue and calm.	Spring Lake near Meadows Discovery Center (#9)
The water is very clear.	Spring Lake near Meadows Discovery Center (#9)
This seems to be a very clean and well-balanced ecosystem.	Spring Lake near Meadows Discovery Center (#9)
Water is still, feel closer to nature, beautiful nature scape, welcoming, easy to access.	Spring Lake near Meadows Discovery Center (#9)
What stands out is how blue the water is in the parts that aren't covered in seaweed sludge on the surface.	Spring Lake near Meadows Discovery Center (#9)
Amazing, verdant, peaceful, free.	Meadows Center Wetland Boardwalk (#10)
Beautiful natural area with great wildlife viewing, but not easily accessible because of university parking.	Meadows Center Wetland Boardwalk (#10)
Beauty of nature. I hope we can save it for future generations.	Meadows Center Wetland Boardwalk (#10)
Birds and fish and flowers.	Meadows Center Wetland Boardwalk (#10)
Cal, relaxing, educational, inspiring, stress reducing. Distracting due to road noise.	Meadows Center Wetland Boardwalk (#10)
Great habitat for birds. Road noise. Loved the walkways.	Meadows Center Wetland Boardwalk (#10)
Healthy fish, turtles, fauna, and clear water. So thankful for it all!	Meadows Center Wetland Boardwalk (#10)
How can I get involved?	Meadows Center Wetland Boardwalk (#10)
How naturally and peaceful this place is even though we are surrounded by man made things, like cars, streets, etc.	Meadows Center Wetland Boardwalk (#10)
I have not seen a waterscape before, very cool. :)	Meadows Center Wetland Boardwalk (#10)
I live in urban San Antonio, and most of our waterways have been converted to commercialized or aesthetic spaces, taking away from the natural beauty of these areas. The Meadows Center Boardwalk was a great example of how to make a waterscape accessible to tourists while maintaining the natural landscape of it.	Meadows Center Wetland Boardwalk (#10)
I love how comfortable the wildlife is in this environment.	Meadows Center Wetland Boardwalk (#10)

Table A2. *Cont.*

Comment	Site
I love the river and I hope we can continue to protect it. It would devastate me if all this current construction and influx of people destroyed our river. It's a sacred land and we need to protect and provide for it at all costs!!	Meadows Center Wetland Boardwalk (#10)
I love the spices in reserve and the way it's taking cake of the turtles and plants.	Meadows Center Wetland Boardwalk (#10)
It's so beautiful.	Meadows Center Wetland Boardwalk (#10)
Just beautiful.	Meadows Center Wetland Boardwalk (#10)
Lily pads and algae.	Meadows Center Wetland Boardwalk (#10)
Loud with cars and trucks. Cicadas are loud too but they belong here.	Meadows Center Wetland Boardwalk (#10)
Natural, ecologically mindful.	Meadows Center Wetland Boardwalk (#10)
Noise is a downfall of location, but the wetlands are calming and relaxing.	Meadows Center Wetland Boardwalk (#10)
Not polluted.	Meadows Center Wetland Boardwalk (#10)
The accessibility of the boardwalk stands out most to me.	Meadows Center Wetland Boardwalk (#10)
The beauty of it and easy viewing of wildlife.	Meadows Center Wetland Boardwalk (#10)
The clear water and absence of trash is remarkable. We could see the different fish nesting and a multitude of turtles. The children were excited to spot so many large gar, and the cichlids had amazing colors that I have not seen anywhere else.	Meadows Center Wetland Boardwalk (#10)
The clear water definitely has a lot of life from underwater life to plants.	Meadows Center Wetland Boardwalk (#10)
The only thing that detracts is the noise from I-35.	Meadows Center Wetland Boardwalk (#10)
The water lilies have taken over Aquarena Springs!	Meadows Center Wetland Boardwalk (#10)
The wetland like landscape.	Meadows Center Wetland Boardwalk (#10)
This is one of my favorite spots. There are not a lot of people which I really enjoy. The only thing that takes away from it is the highway. (I wish it wasn't built).	Meadows Center Wetland Boardwalk (#10)
Unfortunately, there is a lot of noise pollution in this area.	Meadows Center Wetland Boardwalk (#10)
Very relaxing but the car sounds from nearby roads/highway diminish effect on this side of the spring lake.	Meadows Center Wetland Boardwalk (#10)
Water is so clear!! Some plants and algae obscure water but that's natural for the animals. It's really clear and pretty and calm.	Meadows Center Wetland Boardwalk (#10)
What stands out most is how clear the waterscape is. Despite the depth, the algae and grass allow for a very serene waterscape.	Meadows Center Wetland Boardwalk (#10)
White people used slaves to build a dam here and impede the free flow state of the river, fuck you.	Meadows Center Wetland Boardwalk (#10)
Wildlife.	Meadows Center Wetland Boardwalk (#10)
Wildlife is evident but traffic noise is distracting.	Meadows Center Wetland Boardwalk (#10)
Algae.	Purgatory Creek at Bicentennial Park (#11)
Aquatic plant life.	Purgatory Creek at Bicentennial Park (#11)
I like the hill scape beyond the river. The area between the road and the river is a bit overgrown and could benefit from some tending to allow for better interaction with the landscape.	Purgatory Creek at Bicentennial Park (#11)

Table A2. *Cont.*

Comment	Site
I love jogging through here with my boyfriend, as well as tubing up stream.	Purgatory Creek at Bicentennial Park (#11)
I really like watching the water runoff from the rain mix in with the clear(er) water.	Purgatory Creek at Bicentennial Park (#11)
It's cool.	Purgatory Creek at Bicentennial Park (#11)
It is just a beautiful place.	Purgatory Creek at Bicentennial Park (#11)
It is still because it seems to be an offshoot and not have much flow.	Purgatory Creek at Bicentennial Park (#11)
It's a little stagnant and murky.	Purgatory Creek at Bicentennial Park (#11)
It's beautiful in that a public access bridge is above it and it connects to the river, which is visible from here, and it's flowing and beautiful.	Purgatory Creek at Bicentennial Park (#11)
Looking great but a bunch of green algae is forming at the banks on the surface.	Purgatory Creek at Bicentennial Park (#11)
Lots of large carp and tilapia today.	Purgatory Creek at Bicentennial Park (#11)
Nice day.	Purgatory Creek at Bicentennial Park (#11)
Other than non-native plants, this is a very lively and natural spot. Others may disagree, as it has more aquatic growth than many people prefer.	Purgatory Creek at Bicentennial Park (#11)
Sessom Creek * looks cleaner than usual. Less algae, making it more appealing * This participant typed Sessom Creek, but was visiting Purgatory Creek.	Purgatory Creek at Bicentennial Park (#11)
Some trash.	Purgatory Creek at Bicentennial Park (#11)
The fish eating off the top of the water was the best.	Purgatory Creek at Bicentennial Park (#11)
The red flowers near it.	Purgatory Creek at Bicentennial Park (#11)
There are many beautiful shades of green and signs if wildlife. The water is clear enough to see the bottom, rocks, fish, flora, and other detritus. There are dragon flies and other insects that are very pleasant. I do see some trash and that is why I am a little disgusted.	Purgatory Creek at Bicentennial Park (#11)
This area doesn't feel very safe, and the water is stagnant. The bridge is pretty, but the surrounding features have large piping, and it looks somewhat like a work in progress with the pipes and large cut stones. It's quite dim at night.	Purgatory Creek at Bicentennial Park (#11)
This area seems more stagnant than others. but it is gorgeous and feels very set apart from the city.	Purgatory Creek at Bicentennial Park (#11)
Trash in the water and it seemed still. Otherwise very nice part of our park walk.	Purgatory Creek at Bicentennial Park (#11)
Very quiet and nice. I've seen deer at this location before and stand and look out once and a while.	Purgatory Creek at Bicentennial Park (#11)
Very quiet and peaceful, but the water seems stagnant and there is a scum on the surface.	Purgatory Creek at Bicentennial Park (#11)

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Article

The SmartLandMaps Approach for Participatory Land Rights Mapping

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Abstract: Millions of formal and informal land rights are still undocumented worldwide and there is a need for scalable techniques to facilitate that documentation. In this context, sketch mapping based on printed high-resolution satellite or aerial imagery is being promoted as a fit-for-purpose land administration method and can be seen as a promising way to collect cadastral and land use information with the community in a rapid and cost-effective manner. The main disadvantage of paper-based mapping is the need for digitization to facilitate the integration with existing land administration information systems and the sustainable use of the data. Currently, this digitization is mostly done manually, which is time-consuming and error-prone. This article presents the SmartLandMaps approach to land rights mapping and digitization to address this gap. The recording involves the use of sketches during participatory mapping activities to delineate parcel boundaries, and the use of mobile phones to collect attribute information about spatial units and land rights holders. The digitization involves the use of photogrammetric techniques to derive a digital representation from the annotated paper maps, and the use of computer vision techniques to automate the extraction of parcel boundaries and stickers from raster maps. The approach was deployed in four scenarios across Africa, revealing its simplicity, versatility, efficiency, and cost-effectiveness. It can be regarded as a scalable alternative to traditional paper-based participatory land rights mapping.

Keywords: land administration; paper map digitization; cadastral boundary extraction; vectorization; sketch maps; fit-for-purpose; participatory mapping; open data kit (ODK)

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1. Introduction

Land rights mapping helps to establish and document secure land tenure, ensuring that individuals and communities have the legal recognition and protection of their rights to use, occupy, and benefit from land. It provides a clear record of land ownership, boundaries, and associated rights, reducing the risk of land disputes, encroachments, and forced evictions.

There are several innovative tools and technologies that can be used for land rights mapping. These tools leverage advancements in remote sensing, geographic information systems (GIS), and data analysis to improve the accuracy, reliability, efficiency, and transparency of land rights mapping processes [1,2]. Examples of innovative tools and technologies are manifold and include high-resolution satellite imagery and aerial imagery to capture detailed information about land cover, land use, and boundaries [3]; Unmanned Aerial Vehicles (UAVs) providing a flexible, cost-effective and timely collection of imagery of small to medium-sized areas [4]; GIS software providing a powerful platform for integrating, analyzing, and visualizing land-related data; and mobile applications allowing for GNSS-supported field data collection and mapping.

Currently, millions of land rights worldwide remain digitally undocumented. Walking the boundaries of each owned property to record their spatial extent would not only be time-consuming but also impractical in some cases (e.g., huge plantations, swamps, dangerous areas). Hence, the challenge of documenting all land rights worldwide cannot be met with a classical surveying approach alone but requires complementary approaches. Participatory mapping using sketches presents an opportunity in this context. It can not only speed up the data collection process but also help capture local spatial knowledge from stakeholders and increase the community's confidence in the mapped information [5].

There are at least three approaches used to record spatial information via the use of sketches: *digital-sketching* (delineating the boundaries of a geographic entity is done with the help of a digital map, see, e.g., Refs. [6,7]); *analog-freehand-sketching* (the sketch is produced freehand on paper and no background map is used during the sketching, see, e.g., Ref. [8]); and *analog-sketching-on-map* (sketching is done over a georeferenced paper map, usually an aerial orthophoto, see, e.g., Ref. [9]). The three approaches have both advantages and disadvantages. As for digital sketching, the advantages include the efficiency of the data processing (i.e., the data is recorded digitally and can be automatically post-processed, analyzed, and combined with other datasets). The disadvantages are the learning curve (i.e., there is a need to teach people how to manipulate digital maps) and most importantly the logistics (i.e., either a whole community needs to be moved to the location of the Maptable [7,10] used to record the boundaries, or the Maptable needs to be transported to different locations). The key advantage of drawing on paper maps is that the logistics are much easier to cope with (see, e.g., Ref. [11]). Besides, it removes the technical hurdles of recording data, which means that the participants can focus entirely on the discussion about their surroundings and the matter at hand, rather than focusing on their interaction with a computer [11]. Finally, drawing on paper maps requires fewer instructions for the participants [11], and having a gentle learning curve for the participatory mapping activities is desirable so as to 'leave no one behind'. The key disadvantage of drawing on paper maps is the need for digitization to bring the data into a digital format. Currently, this digitization is mostly done manually, which is time-consuming and error-prone. The SmartLandMaps approach aims to address that gap.

The analog-freehand-sketching approach and the analog-sketching-on-map approach share the abovementioned advantages and disadvantages of drawing on paper. The main difference is that the use of aerial photographs or orthophotos as reference surfaces in the sketching-on-map strategy facilitates the preservation of spatial/geometric aspects of the drawn units. Since our goal in this work was to capture the outlines of spatial units, we followed a sketching-on-map strategy. The contexts of the four scenarios required the use of base maps from different sources (i.e., satellite and drone data providers) to ensure the most appropriate level of spatial detail and timeliness of the data during the participatory mapping activities. The focus of this work is on the following research questions:

- RQ1: How to facilitate scalable land rights recording?
- RQ2: How to automatically extract parcel boundaries from hand-drawn sketches?
- RQ3: How to automatically extract labels from hand-drawn sketches?

RQ1 is addressed through a participatory mapping-based strategy while RQ2+RQ3 are addressed through the SmartLandMaps software for the automatic extraction of parcel boundaries and parcel labels from paper maps. The contributions of this work are lessons learned from deploying the approach in four scenarios (RQ1) and evaluating the digitization software (RQ2+RQ3). As discussed in Ref. [12], cadastral boundaries can be broadly divided into two categories: (i) fixed boundaries, whose accurate spatial position has been recorded and agreed upon and (ii) general boundaries, whose precise spatial position is undetermined. The approach proposed in this work assists the first-time data collection and digitization of *general* boundaries.

The remainder of the article is structured as follows. Section 2 briefly presents related work on fit-for-purpose land administration, community-based mapping and the detection of boundaries from aerial imagery. Section 3 presents the SmartLandMaps approach, with a focus on preparation, the collection of informed consent, the mapping, and the processing of the collected data. The approach was deployed in four scenarios. Section 4 provides information about the study areas while Section 5 presents the evaluation results. Section 6 revisits the research questions and Section 7 concludes the article. This paper reuses and extends material from Ref. [13,14].

2. Related Work

2.1. Fit-for-Purpose Land Administration

Fit-for-purpose land administration (FFPLA) aims to close the global tenure security gap by providing secure and sustainable land rights to all members of society, in particular to those in informal or customary land tenure situations. In contrast to traditional (classical) survey approaches, it emphasizes the need for practical, affordable, and scalable solutions that can be implemented in a context-specific manner to meet the diverse needs and realities of different communities. Over the past decade, from its first publication in 2014 [15] and the establishment of basic principles that address spatial, legal, and institutional frameworks, the FFPLA has evolved into a viable concept that is implemented in various contexts [16]. Mapping visual boundaries using high-resolution satellite or aerial imagery is a key element of FFPLA methods for spatial data collection [15] and has been piloted across the globe [17–21].

2.2. Community-Based Mapping

Community-based mapping is a process of visualizing and understanding the physical, social, and economic characteristics of a community through the creation of maps. It involves collecting and analyzing information about the people, places, and resources within a particular community, and then presenting that information in a spatial format. The goal of community mapping is to create a comprehensive understanding of a community's assets, needs, and resources, and to use this information to inform community development, planning, and decision-making processes. Among others, community mapping has the following key qualities:

- Increased spatial knowledge: Community members have a deep understanding of their local area and can provide valuable insights and information that may not be reflected in traditional maps;
- Empowerment [22]: Community-based mapping empowers local residents to take ownership of their geographic information and to share their knowledge and perspectives with others;
- Increased local engagement: By involving local residents in the mapping process, community-based mapping can promote community engagement and strengthen local networks;
- Improved decision-making: Community-based maps can inform local decision-making and planning processes, ensuring that the perspectives and needs of local residents are considered.

Best practices in community engagement and various methods of participatory mapping have a long history in documenting land use and tenure and are used by various, mainly non-governmental organizations (e.g., Community Land Protection Facilitator Guide [23]). However, community mapping approaches have also gained importance in large-scale land tenure documentation projects (e.g., Rwanda) and are promoted as an FFPLA methodology [16,24]. Different tools and approaches can be utilized depending on the context, resources, and capacities [5,8,9]. However, in the realm of land administration, Ho et al. [25] revealed that while technology aims to promote inclusivity, it often falls short due to the lack of proper checks and the failure to view communities as equal partners in knowledge creation.

2.3. Detection of Boundaries Using Machine Learning and Deep Learning

Previous work has investigated the automatic detection of boundaries from aerial and satellite imagery. These boundaries can be either from buildings [26–31] or cadastral boundaries [32–38]. Since the focus of this work is on the automatic extraction of cadastral boundaries, we will now briefly review previous work touching on this topic.

Mango et al. [35] used neural networks to facilitate the process of converting paper-based cadastral maps into digital data. L-CCN was used to detect lines in Ref. [39], and ResNet-50 was used to detect numbers in Ref. [40] with promising results. Fetai et al. [34] used both the U-Net model [41] (open-source) and the ENVINet5 model (proprietary) while training deep neural networks on the task of automatic recognition of visible land boundaries. The areas selected for testing featured agricultural fields, roads, fences, hedges and tree groups. They reported accuracies greater than 95% for both models. Crommelinck et al. [36] used gPb (globalized probability of boundary) to automatically detect contours from orthoimages that show visible cadastral boundaries. They reported errors of omission between 14% and 52%. Crommelinck et al. [32] compared random forest (RF) and convolutional neural networks (CNNs) for the detection of cadastral boundaries and reported accuracies of 41% and 52%, as well as precisions of 49% and 76% for the two methods, respectively. Xia et al. [37] tested the performance of CNNs against MRS (multi-resolution segmentation) and gPb (globalized probability of boundary) for cadastral boundary detection in urban and semi-urban areas. They reported that CNNs outperformed MRS and gPb. The average quality assessment values obtained in their work for the CNNs were 0.79 in precision, 0.37 in recall, and 0.50 in F-measure. Finally, Persello et al. [38] used the SegNet model [42] to learn about the boundaries of agricultural fields in smallholder farms. They reported F-measures higher than 0.60 in their test areas.

Overall, many of the works presented above have relied on deep learning with promising results. Although deep learning models can learn complex characteristics that are challenging to specify manually, one drawback of deep learning methods is that they need large datasets for training. This is not the case in this work, where we only have a small number of instances (see Section 4). By contrast, conventional approaches (e.g., region-based, edge-based, and clustering-based) to image segmentation require less data. Their drawback, however, is the sensitivity to contrasts between objects and the background, and the subjectivity of the parameter selection (see Ref. [43]). We present an edge-based processing pipeline for boundary extraction in Section 3.4. We also report on the performance of the U-Net model [41] and the SegFormer model [44] on the boundary detection task. These two models have proven useful in many scenarios and correspond to the state of the art on semantic image segmentation. The U-net model was trained from scratch using a standard architecture. We fine-tuned pretrained SegFormer models on the sketches collected during the work, in the spirit of few-shot learning [45]. Image segmentation approaches using deep learning were reviewed in Ref. [46]. For a recent review of semantic segmentation in the context of geospatial artificial intelligence, see Ref. [43].

3. Method—The SmartLandMaps Approach

We build upon best practices for community engagement and participatory mapping methods while designing our mapping strategy (Figure 1). The mapping strategy is introduced in this section, with a focus on preparations (Section 3.1), the collection of informed consent (Section 3.2), mapping (Section 3.3), and the processing and digitization of the collected data (Section 3.4). For a discussion of the three pillars of the SmartLandMaps approach (acceptance, efficiency, and flexibility), see Ref. [47].

The recommended mapping process can be divided into three main phases: the preparation phase, the mapping phase, and the processing phase. The preparation phase should start at least six weeks before the mapping phase to ensure enough time for raising the community's awareness and allow for technical preparations. The actual mapping phase relies on a strong commitment from the local community and includes mobilization, an introduction to the mapping activity, obtaining informed consent and the actual collection of spatial and textual data on land ownership and land use. The processing phase starts by tracing validated lines with a black marker, followed by taking photos of the map, which are then uploaded to the SmartLandMaps cloud along with the collected textual information. From here, land data can be fed into a national land administration system and further used for validation processes and issuance of land titles. The entire process requires only a tablet computer or smartphone, no software, and no sophisticated technical skills on the part of the community mappers.

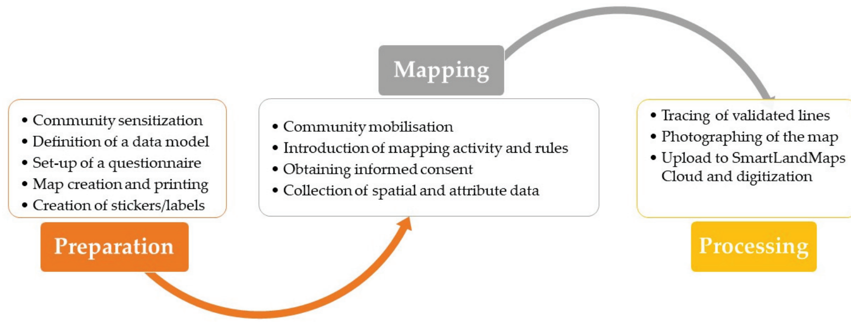

Figure 1. Mapping strategy of the SmartLandMaps approach.

3.1. Preparations

Preparations for community mapping processes are highly important and can significantly influence the success, accuracy, reliability, and effectiveness of the mapping initiative. Several aspects need to be considered to ensure that the process is well-organized, community-driven, and results in accurate, relevant, and impactful mapping outcomes. Table 1 outlines main activities and considerations in chronological order.

The purpose and scope of the community mapping activity should be at the forefront of any further decisions about the mapping process and subsequent preparation. Eight to four weeks before the planned fieldwork, a fieldwork plan should be drawn up. This will include decisions on the extent of the mapping area, a thorough review of existing procedures and practices that may influence the mapping process, and a data model and data collection strategy—all in cooperation and consultation with local partners, i.e., government representatives or local organizations. Once the mission plan has been drawn up, special attention should be paid to sensitizing the community, involving local leaders and community elders and gaining their trust and involvementin the process. If community members understand the purpose and benefits of the mapping activity, they are more likely to participate actively, contribute valuable information and take ownership of the results. The data model and the data collection strategy are introduced and discussed with community representatives. The data model should be appropriate to the mapping activity and local circumstances. Co-designing with local representatives ensures compliance with standards while meeting specific needs.

In addition to planning and consultation with local stakeholders, map production plays an important role. The printed orthophoto is the key mapping instrument, and if the map content or the resolution does not match the scope and the mapping objective, it is unlikely that the mapping activity will be successful. In particular, the selection of a suitable orthorectified image is important, especially in urban areas with multi-storey buildings causing relief displacement. Poor-quality maps can make it difficult to identify properties and respective boundaries. In this regard, the size of boundary objects and parcels should guide a decision on the required spatial resolution. Customary lands with several hundreds of hectares require a different spatial resolution of the base map than small plots in urban surroundings. At the same time, the data source for map creation should match the given timeline and budget. As a starting point, Enemark et al. [48] suggests different scales for mapping applications depending on topography and land use.

Table 1. Preparation steps for community mapping with the SmartLandMaps approach.

What	When	Who	Comments
Definition of the objective of the community mapping activity	8 weeks ahead	All parties involved	What to achieve? Whom to speak to? What challenge to solve?
Definition of the mapping area	6 weeks ahead	Local partner	The area should be accessible, involvement of local representatives is crucial
Decide on and obtain the base data for the maps	5 weeks ahead	Local partner (existing aerial data?), local drone company, satellite data provider	Based on local requirements, financial resources, data availability
Identification of current surveying practices, data models and local requirements	5 weeks ahead	Local partner	Derive from country-specific land policies and survey manuals
Definition of a data collection process (and data model)	4 weeks ahead	SmartLandMaps in consultation with local partners	Based on local characteristics/visual boundaries/mission objective/type of land tenure to be mapped
Creating a field mission plan	4 weeks ahead	All parties involved	Decide on what needs to be done, by whom and with what kind of equipment
Sensitization of local stakeholders in the mapping area	3 weeks ahead	Local partner	Share field mission plan and fine-tune requirements and activities based on local needs
Prepare and print base maps and mapping material	2 weeks ahead	SmartLandMaps and local entity	Decide on layout, stickers and map features based on local circumstances
Circulate the final schedule of all activities	1 week ahead	Local partner	Notify local representatives (and citizens) about meetings and activities

3.2. Informed Consent

Following Bhutta [49], there are four determinants of the process of developing informed consent: (i) information provision and sharing by the research team with the participants and community leaders, (ii) discussion and interaction between researchers and potential participants, (iii) participant understanding, and (iv) acceptance/rejection of participation. To comply with these, we used an iterative model for consent. As discussed in Ref. [50], iterative models of consent are based on the assumption that ethical agreements can best be secured through a process of negotiation that aims to develop a shared understanding of what is involved at all stages of the research process. Hence, participants' agreement is not obtained through one-off (written) agreements, but the consent process is spread throughout the whole duration of the project (i.e., consent is asked on an as-needed basis at different stages of the data collection).

Step 1: Sensitization and information (group consent): Before any data was collected, we informed all participants about the purpose, the procedure, the benefits, and the risks of participating in this research. We mentioned explicitly that the participation is voluntary and that the participants can quit the data collection activity at any time without having to state their reasons for doing so. Furthermore, we elaborated on the protection of any data collected and outlined the anonymization procedure. On site, a script detailing these aspects was developed and read out loud to the group. We then gave room for questions and gave the possibility for the attendants to leave the group if they did not want to participate. With this procedure, a first oral group consent was collected and the mapping and sketching could start with the persons manifesting their consent by staying.

Step 2: Participatory mapping of the parcel boundaries: The group that consented in step 1 discussed and marked the boundaries of their respective plots on the printed orthophoto provided by SmartLandMaps. Their discussions were not recorded. To protect the anonymity of the participants, we took pictures without participants' faces (i.e., hands drawing on the paper sheet), photographing only the hands of those who consented. In this step, no additional personal information is collected.

Step 3: Collection of personal information (oral informed consent): After the discussion and sketching session, we collected information on land ownership. Prior to starting the digital questionnaire, we again explained that the data collection is voluntary, that they can withdraw their participation at any time, and that they have to orally consent to continue with the questionnaire. We recorded the oral informed consent with a voice recorder, which was integrated into our questionnaire. The questionnaire did not foresee any obligatory fields regarding personal data. Hence, the participants could choose which data they wanted to provide and skip as many questions as they wished[1].

The above procedure (steps 1 to 3) was followed in the Benin scenario because the data collection in Benin was for research purposes only. In Chad and Sierra Leone, a slightly different procedure was followed in steps 1 and 3, as the data collection was embedded in a project setting with its own requirements for informed consent. In all cases, however, consent was sought in the local language of the community members as part of the voluntary group consent process.

3.3. Mapping

The community mapping process involves introducing community leaders to the process, often led by a local trusted body such as an NGO. Mapping materials and technology are introduced, questions are answered, and a mapping plan is developed. Meeting places are chosen at known meeting points within the mapping area to ensure that everyone can reach them easily. Mapping rules are agreed upon with local stakeholders. In some cases, separate mapping sessions for men and women may be planned to ensure that everyone can attend and actively participate in the mapping activity. Conflict resolution measures should be put in place, such as field-based boundary validation using GNSS technology if the boundary cannot be clearly defined from the orthophoto alone. According to Ref. [48], the field adjudication and recording process has three main elements: the location of the land right to be enjoyed, the nature of the right, and the person holding the right. The field adjudication process was supervised by a trusted intermediary such as a village elder or community official. It should be noted, however, that no title documents were issued as the field data collection was for research and demonstration purposes only, with an emphasis on the participatory process and technical feasibility.

Boundary data collection: A mapping assistant leads the mapping activity. The mapping assistant could be a para surveyor or a trusted person who knows how the mapping process works and what particular attention should be paid to the cartographic requirements and communication during the participatory mapping activity. In any case, he or she must take a neutral position. During the process, community members can also take charge of the mapping under the supervision of the mapping assistant. Property owners use landmarks such as churches, intersections, roads, sacred places, or schools to orient themselves on printed maps. If necessary, the mapping assistant will support the identification of landmarks and visible boundaries. Corner points of the plot are then marked either with small sticky dots or with dots drawn on the map with a ballpoint pen. Additional questions might be asked to confirm the location of the parcel such as: "Is this tree on your neighbor's plot, or does it belong to your plot? How many houses are on your plot?". The mapping assistant then connects the points with the help of a ruler and a ballpoint pen so that an area is created. When the property owner is satisfied with this, a spatial ID is assigned and a label is attached to the parcel that was just determined.

Administrative data collection: We used an Android App to perform the data collection. The Android App (Figure 2) was customized from the ODK collect app[2]. We created all questionnaires for the field studies ourselves using ODK Build. After the offline data collection in the field, the data is sent to a server once an internet connection is available.

We have our own server, located currently in a cloud from the provider DigitalOcean[3]. We chose DigitalOcean because it was recommended by ODK Collect. It has proven to be reliable throughout the whole project (18 months of testing). The data can be downloaded as a CSV (Comma Separated Values) file from our own ODK server. There is also the possibility of accessing the data from an API (Application Programming Interface). We have written a code (Python) that does the conversion from CSV to JSON (JavaScript Object Notation). Since the boundaries are extracted as JSON data as well, this enables the merging of the boundaries and administrative data using the parcel IDs obtained from the sticker extraction process (Section 3.4).

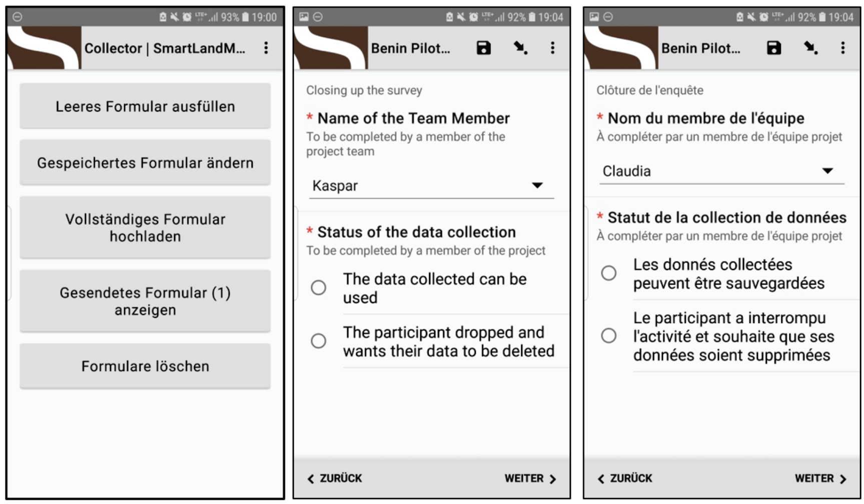

Figure 2. Screenshots of the Android App for data collection. Landing page of the app (**left**); an example of a question asked in English (**middle**); question translated in French (**right**).

3.4. Processing and Digitization

The processing pipeline involves several steps and algorithms. To convert the paper map to a digital format, the map is photographed with a consumer-grade camera, taking overlapping, non-tilted images. This allows the photos to be fed into a photogrammetric/structure-from-motion pipeline to produce a georeferenced, orthorectified image of the map. The creation of vector data from the georeferenced digital images is done by Python programs running from a Google Colab notebook. The boundaries are extracted from the images as binary rasters using computer vision algorithms and watershed segmentation. The binary raster is used as a basis for creating polygons, which are stored in a GeoJSON file. Another Python program deals with detecting printed numbers on the stickers, which are used for spatially joining attribute data to the vectorised parcels. The programs mentioned above are based on open-source libraries, which include OpenCV and skimage for image manipulation, gdal and pyproj for handling map projections and transformations, and shapely for constructing polygon geometries. For text recognition on the stickers, we used the Google Tesseract Optical Character Recognition Engine.

Creation of a georeferenced orthorectified image: The digitization starts with the processing of all photos taken from the sketched map using WebODM[4], with the aim of generating an orthophoto from the input data. The processing pipeline proceeds from motion structure, multi-view stereo, meshing, texturing, and ends with orthophoto generation [51]. As the photos of the map do not have usable geotags, the generated output is georeferenced using pre-existing markers (small red crosses) on the printed map. The location of at least five evenly distributed markers and the corresponding coordinates in the target reference system are used to apply the Helmert transformation. A georeferenced orthorectified image of the annotated printed map is then generated and used for boundary detection and vectorization.

Boundary detection: The boundary detection is performed iteratively on patches of the original image, which are merged into a single binary image as an output result. The input image is first blurred using a 5 × 5 Gaussian filter, then it is converted into grayscale. These steps reduce noise and simplify the subsequent edge detection process. Edge detection is performed using the Canny algorithm, which detects significant changes in intensity. Next, Euclidean distance transformation is applied, which computes the distance of each pixel to the nearest edge, providing a measure of proximity to the boundaries. Using the distance-transformed image, peaks are detected to identify potential boundary locations. The watershed algorithm is applied to the negative of the distance-transformed image, utilizing the previously detected peaks as markers. Additionally, a binary mask is used to specify which regions of the image should be labeled. This binary mask is created by thresholding the grayscale image with a user-defined threshold value, which is one of the most important parameters. The threshold value was held constant at 60 for all techniques. The result is a segmented image with distinct labeled regions. Finally, all non-zero labeled regions are assigned a value of 255, while the background is assigned a value of 0, creating a binary image with the detected lines. In order to eliminate small gaps due to missed pixels close to patch edges and corners, this process is done again using a different patch arrangement. This time, padding is added to the image on the top and left sides, in a width equal to half the patch size. After the second binary image is obtained, the padding is cropped and the two results are combined using a bitwise OR operation. In the last step, dilation is applied using a 5 × 5 kernel to close the remaining small gaps in the boundaries. The steps described here share some similarities with the workflow presented in Ref. [52], but there are two key differences: no assumption that land parcel boundaries are straight lines and no use of the Hough transform during the process.

Vectorisation: The vectorisation of parcel boundaries starts with reading in the binary mask and applying a skeletonization algorithm, which shrinks all lines to a minimum width. Next, using OpenCV's findContours() function, the contours of the shrunk lines are detected and filtered so that only inner contours remain. This means that all gaps in parcel boundaries have to be closed in order to get a contour from the parcel. Using gdal.Info, georeferenced coordinates and coefficients are obtained from the original image, which are then applied to create georeferenced polygons. The script iterates over the contours and creates UTM polygons using Shapely's Polygon function. The polygons are transformed into WGS84 with pyproj, and are filtered by their geodetic area. We chose 50 m^2 as the lower threshold. Then, a GeoJSON FeatureCollection is created with two predefined attributes, parcelID (set to an integer starting from 1) and parcelType. The script permutes over the coordinates and creates a JSON-compatible geometry object for each polygon. The output is written into a GeoJSON file.

We have tested two different vector post-processing approaches in order to minimize the deviation between the generated polygon shapes and the original boundaries. Figure 3 illustrates the effect of both methods. The first method (Figure 3, left) creates a minimum area convex hull over the raw polygons by utilizing Shapely's convex_hull method. The program then removes overlapping areas and returns a new dictionary with all the features. This approach works generally well, eliminating small holes and producing straight polygon boundaries. The drawback of this method is that it cuts corners for individual concave polygons, therefore, it produces wrong boundaries. These polygons either need manual editing or have to be supplied to a fixing algorithm, which subtracts the largest polygon out of the difference between the pre-processed and post-processed geometries. The second approach (Figure 3, right) first filters the points of the raw polygons to only keep the exterior ring, which eliminates all possible holes. Generalization and cleaning are done by GRASS GIS commands, which are invoked from a GRASS session by utilizing the grass_session Python library. This requires GRASS to be installed on the engine where the script is running. After creating a custom Session instance, we open a new mapset and import the raw polygons GeoJSON with the v.in_ogr command. A minimal snapping tolerance (1×10^{-10}) is applied, which fixes some topological errors. Next, we perform Douglas–Peucker generalization by using v.generalize. The generalization threshold is adjustable and depends on the sizes of the parcels and we have decided to use 5×10^{-6}. The v.generalize command also creates polygons to fill small gaps that happened during the polygon creation. v.clean dissolves these small polygons into an adjacent one with the largest common boundary. v.out_ogr creates a GeoJSON output of the final result. Compared to the convex hull approach, GRASS retains a more accurate shape for the polygons, especially concave ones, but can fail to straighten the boundary at noise-related bends and errors. Preliminary testing [14] has shown that the optimal threshold for boundary extraction is dependent on the image. This is also the case for the optimal parameter for the generalization algorithm. Ideally, these parameters should be adapted based on the scenario. Nonetheless, this is not practical for comparison activities across all scenarios. Hence, we chose two values for the comparative assessment in this article based on preliminary tests: 60 as a threshold value for the boundary extraction and 5×10^{-6} as a generalization threshold for the vectorization. We are aware that this inevitably flavors some methods in some conditions to the detriment of others.

Figure 3. Examples of the convex hull method and the GRASS method, respectively.

Sticker detection: Sticker detection is performed by first filtering the RGB channels of the image so that the resulting binary image only contains the stickers as white pixels and everything else as black. For this thresholding, a minimum and a maximum value (0–255) must be specified for all 3 channels as the input parameters. As we had bright yellow stickers, we used the following values: Red—between 160 and 255, Green—between 150 and 255, and Blue—between 0 and 120. After filtering, morphological closing and blurring are applied to close holes and reduce the noise. Next, OpenCV's findContours() function detects all contours and keeps only the ones above a size threshold. For each contour, an algorithm creates an approximate polygon, which is then used for determining a minimum area rotated rectangle. The coordinates of the central point are saved for the GeoJSON creation in a list. Optical Character Recognition requires numbers to be aligned horizontally. For this reason, the rotated rectangles are rotated back to horizontal, resulting in a clip of the original image, on which the numbers are either in the desired position or upside down. We use an asterisk as the last character of each text on the stickers (see Figure 4, left), which, if not detected, indicates that the sticker is upside down and the snippet needs to be flipped.

During the rotation process, a black padding is added to maintain a rectangle shape by using the OpenCV function imutils.rotate_bound. As we are only interested in the center of the snippets, contour detection and polygon creation are performed again, and the snippets are cropped by this polygon. The resulting image is now ready for OCR to be applied. To increase efficiency, detection is performed five times on different resized versions of the image, in the range where performance is best. A function analyses the text and returns an assumption parameter, whether the detection was successful or not. Based on the five results, the program chooses the mode value from the ones labeled good (if any). The output GeoJSON file is a FeatureCollection containing all detected stickers as point features with the detected number and the assumption as parameters (Figure 4).

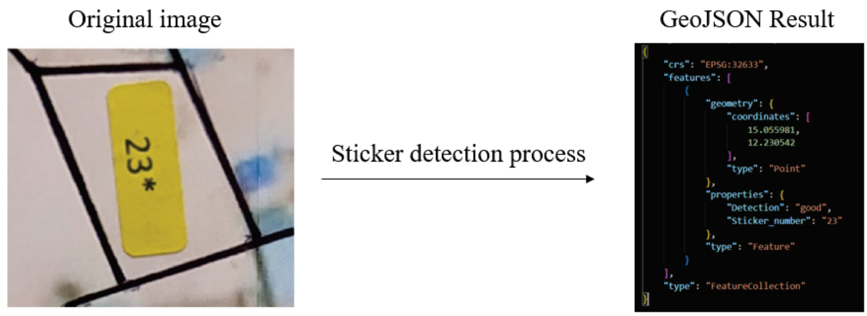

Figure 4. An example of the output from the sticker detection process.

4. Study Areas

The data input for this paper comes from four different scenarios, including projects in Benin, Chad, and Sierra Leone. The mapping activity was carried out by organizations partnering with SmartLandMaps in all three countries, each with its own unique history and challenges. In Benin, a centralized land administration system is being established, with mapping supported by the Dutch-funded Land Administration Modernisation Project [53]. Sierra Leone faces problems of land grabbing [54] and is working on land tenure security through novel land policy reforms and major donor funding through the World Bank's Land Administration Project. Chad is tackling challenges such as slow mapping and land conflicts, with support from the Dutch Ministry of Foreign Affairs' LAND-at-scale program. As described in Table 2, mapping activities in these countries have involved collaboration with local communities, government agencies, and technology providers.

Table 2. Characteristics of the study areas, taken from Ref. [14].

	Benin	Chad	Sierra Leone
Partners involved	Kadaster International, VNG International, YILAA	Kadaster International, Government of Chad, esri North Africa, Trimble, University of Twente	FIG YSN VCSP, Trimble, Ministry of Land, Housing and Country Planning
Date	1–9 February 2022	11–12 October 2022	24–25 January 2023
Orthophoto	UAV-based orthophoto, 1.8–2.3 cm	MAXAR, 50 cm	MAXAR, 50 cm
Land use class	Urban residential and rural residential	Peri-ruban residential	Rural agroforestry

The land-use context, as well as the land tenure system and the size of the spatial units, were heterogeneous across the scenarios. In Benin, the data collection took place in an urban setting with private ownership (Seme-Podji) and in a rural setting with individual and group ownership (Zè) [13]. In Chad, SmartLandMaps was tested alongside other forms of cadastral surveying and mapping in a peri-urban environment near the capital N'Djamena, characterized by private property rights [55]. The context in rural Sierra Leone was very different, with predominantly agroforestry land use and a customary tenure system, i.e., family lands averaging several hundred hectares. Looking at Figure 5, it is clear that the presence of visible boundaries was different in each scenario, allowing different strategies to be observed in how community members deal with them. For more information on the contextual specifications, data collection, observations and results, see Ref. [14].

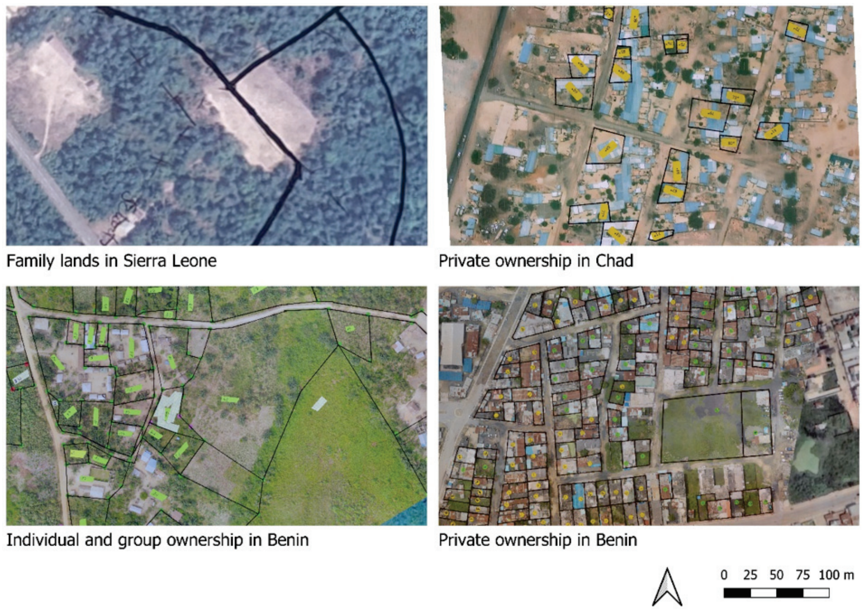

Figure 5. An excerpt of the community mapping outputs. The scale is the same for all maps.

5. Evaluation

The evaluation touches upon five aspects: the digitization performance, cost and time considerations, the simplicity of the mapping activity for participants, the inclusiveness of the whole approach, and its versatility.

5.1. Digitization Performance

The tests were done in two steps: first a comparison of the convex-hull-based approach and the Douglas–Peucker approach to find out the best between the two, and second an assessment of the impact of the pre-processing strategy (Blurring or Mean-Shift) on the performance of the best approach. Table 3 shows the results. Overall, the test on the four scenarios (Benin urban, Benin rural, Chad, and Sierra Leone) show that our method can achieve excellent performance on different datasets in a quick timeframe. Depending on the size of the input image, the boundary detection took about 3 min (Chad-North scenario) to 16 min (Benin rural scenario). The vectorization only took 1 to 3 min, similar to the sticker detection. Since the performance values were obtained without adjusting the threshold parameter (boundary extraction algorithm) and the generalization parameter (vectorization algorithm), the values in Table 3 should be seen as the *lower bounds* of the final performance. That is, calibration specific to a scenario can further increase them.

Table 3 also presents the performance results for model training (U-Net) and model fine-tuning (SegFormer model, nvidia/mit-b1) on the dataset. As discussed in Section 2.3, deep learning models are not entirely appropriate for the current context given the small amount of data points. Nonetheless, since U-Net and SegFormer stand for the state of the art in image segmentation, we trained the two models to use their results as a baseline for the comparison of the proposed algorithms. The dataset from the Benin urban scenario, which had the largest number of parcels (see Figure 5), was used for training. The outcome map was manually labeled using two classes (background and boundary) and then divided into patches (512, 512, 3). This resulted in a total of 1260 patches. About 70% of these patches were used for training, 20% for validation, and 10% for testing. The dataset was not balanced (723 patches ∼57% showed a boundary and 537 patches ∼43% did not show any boundary). We did not use data augmentation. The metrics obtained on the validation dataset during training were: 99% (accuracy, U-Net); 48% (Mean IoU, U-Net); 92% (accuracy, SegFormer); 86% (Mean IoU, SegFormer). Examples of prediction outcomes per patch on the test dataset (i.e., unseen patches) are shown in Figure 6. We fine-tuned both nvidia/mit-b0 and nvidia/mit-b1. Since we obtained slightly better results with the nvidia/mit-b1 model, we only report the results for nvidia/mit-b1.

In the case of the Benin and Chad scenarios, blurring with Douglas–Peucker generalization (using GRASS) produced the best performance regarding boundary detection, with a 0.99 F-measure. We can see a slight improvement in both precision and recall compared to the Convex hull method. The most significant difference is observed with the Benin urban scenario, where the number of true positives exceeds the Convex hull result by 6, while the numbers of false positives and negatives are simultaneously lower. In all cases, there have been no invalid geometries using GRASS, as opposed to a few cases with the Convex hull. Both approaches led to a significant number of features that require manual editing, which suggests that both methods call for further improvements. Mean-Shift proved to be less efficient with lower recall values than Convex hull and Douglas-Blur for both Benin images. In the case of Chad, where all three methods produced the same F-measure, the number of features needing to be edited is almost double that of the other methods.

Results show a much lower efficiency for all the above-mentioned methods in the case of the Sierra Leone scenario. The cause of this issue is linked to the boundary detection threshold parameter, which we left unchanged for the sake of comparison. As this image is generally brighter, a higher threshold would have been necessary, as it is directly linked to the detection of lines. Using image correction techniques (such as brightness and contrast adjustment), this concern could be addressed. This also indicates that without raster pre-processing, choosing the optimal boundary parameter is essential.

Out of the two neural networks, U-Net produced far better results than the SegFormer model. It managed to obtain the best F-measure for Sierra Leone with 0.56 and yield 0.91 for the Chad scenario. Arguably, these results do not come close to our best-performing method with optimal parameters, but they show that U-Net could be a promising alternative in the future. Nevertheless, efficiency is vastly dependent on the training and testing data, and detecting boundaries over different backgrounds remains a challenge.

The Benin scenarios were excluded from the sticker detection, as they only contain stickers with handwritten digits, in a non-standardized form. In the case of the Chad scenario, there was only 1 missed sticker out of the 52 cases, which means 0.98 accuracy and complete precision. However, in the Sierra Leone scenario, none of the 11 stickers were detected. The reason behind this poor result is the same as mentioned above, namely the unchanged parameters for two images with different characteristics. The sticker detection can achieve great proficiency, but similarly to boundary vectorization, it relies on the appropriately chosen parameters unless raster pre-processing is involved.

5.2. Cost and Time Considerations

The costs and time needed for capturing boundary data determine, whether an approach used in a small pilot project is scalable, i.e., whether it could eventually be rolled out for larger regions or be used to create a country-wide cadaster. A cadastral project can be called "fit-for-purpose" if it is implementing a good compromise between the desired positional accuracy on the one hand, and the available resources in terms of money and time on the other hand. Our practical experience in the mentioned four scenarios showed that the SmartLandMaps approach is suitable for projects with comparatively low costs per parcel and time to complete a larger data capture exercise. In Benin and Chad, we were able to capture with one field team up to 200 parcels per day when using the SmartLandMaps approach, while the same team achieved only 20–30 parcels when walking to and measuring the boundary points of each parcel with a handheld device and a GNSS antenna. The costs incurred for the data capture with the SmartLandMaps approach averaged from 5 to 10 USD/parcel including the drone image and the processing of the data in the SmartLandMaps Cloud, while the direct surveying with the handheld device we did for comparison resulted in costs from 20 to 50 USD/parcel. These costs are in line with the unit costs stipulated by UN-Habitat, FIG, and GLTN in their framework for costing and financing land administration services (CoFLAS [56]). From these observations on costs/time and the digitization performance (Section 5.1), we can state that the Smart-LandMaps approach is fit-for-purpose: It is reliable, faster, low cost (4–5 times cheaper), and scalable (adding more field teams does not necessitate much investment in training), but requires, as a compromise, that reachable positional accuracy is 0.8 to 1.5 m lower than the positional accuracy of traditional surveying.

Table 3. Digitization performance (TP: True Positives; FP: False Positives; FN: False Negatives; NG: Features with NULL geometry; NE: Needs to be edited; N/A: Not applicable). The highest metric for a scenario is highlighted in grey.

	TP	FP	FN	NG	NE	Precision	Recall	F-Measure	Scenario
slm-Convex-hull	191	4	10	4	30	0.98	0.95	0.96	Benin urban
slm-Douglas-Blur	197	1	4	0	33	0.99	0.98	0.99	
slm-Douglas-Mean-Shift	161	0	42	0	70	1.00	0.79	0.88	
slm-Convex-hull	74	0	3	1	8	1.00	0.96	0.98	Benin rural
slm-Douglas-Blur	75	0	2	0	8	1.00	0.97	0.99	
slm-Douglas-Mean-Shift	71	0	6	0	11	1.00	0.92	0.96	
unet-Convex-Hull	19	2	58	0	2	0.90	0.25	0.39	
unet-Douglas	19	2	58	0	2	0.90	0.25	0.39	
segformer-Douglas	8	0	69	0	2	1.00	0.10	0.19	
segformer-Convex-Hull	8	0	69	0	2	1.00	0.10	0.19	
slm-Convex-hull	51	0	1	1	9	1.00	0.98	0.99	Chad north
slm-Douglas-Blur	51	0	1	0	8	1.00	0.98	0.99	
slm-Douglas-Mean-Shift	52	1	0	0	15	0.98	1.00	0.99	
unet-Convex-Hull	43	0	9	0	5	1.00	0.83	0.91	
unet-Douglas	44	0	8	0	3	1.00	0.85	0.92	
segformer-Douglas	13	0	39	0	2	1.00	0.25	0.40	
segformer-Convex-Hull	13	0	39	0	3	1.00	0.25	0.40	
slm-Convex-hull	4	0	8	0	4	1.00	0.33	0.50	Sierra Leone
slm-Douglas-Blur	4	0	8	0	1	1.00	0.33	0.50	
slm-Douglas-Mean-Shift	1	0	11	0	0	1.00	0.08	0.15	
unet-Convex-Hull	5	1	7	0	3	0.83	0.42	0.56	
unet-Douglas	5	1	7	0	0	0.83	0.42	0.56	
segformer-Douglas	0	0	12	0	0	0.00	0.00	0.00	
segformer-Convex-Hull	0	0	12	0	0	0.00	0.00	0.00	
Sticker detection	0	0	0	N/A	0	0.00	0.00	0.00	Sierra Leone
Sticker detection	51	0	1	N/A	0	1.00	0.98	0.99	Chad north

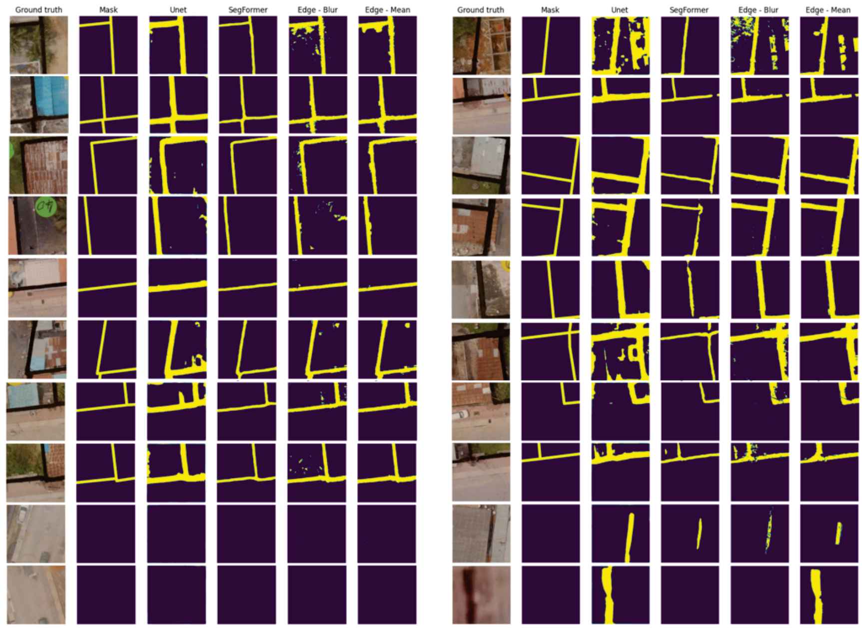

Figure 6. Examples of boundary predictions on the test dataset. Patches where the whole boundary is correctly predicted (**left**); patches where the boundary is not correctly predicted for at least one of the techniques (**right**). The boundaries predicted at the patch level are then merged (and post-processed to close gaps) to obtain the parcels for a whole study area.

5.3. Simplicity

The main mapping activity required only a pen, a printed orthophoto, and a mobile device with a camera. Because SmartLandMaps allows for an almost fully automated digitization workflow, mapping assistants need only very basic skills to facilitate the mapping activity, but also to initiate digitization. Simplicity applies not only to the mapping process, but also to the ease with which community members engage with the map as an accessible and easy-to-understand method of collecting spatial information. According to a survey in Benin (n = 388), almost 90% of participants reported that they found it either very easy (65%) or fairly easy (22%) to mark the boundaries of their parcels on the map [13]. However, it is important to note that this result can be influenced by the type of land cover and land use. Adjustments to the ease of mapping may be necessary in cases of homogeneous land cover [57].

5.4. Inclusiveness

Inclusiveness can refer to the diversity of tenure systems or to the dimension of people involved. In the three study sites, SmartLandMaps proved to be inclusive of both formal and informal tenure systems. As for the dimension of inclusiveness of the mapping process, we observed all kinds of participants in the mapping session, including women and men, old and young, people with disabilities, educated and literate, as well as illiterate and less educated people. However, it should be noted that future data collection campaigns should consider measures to further increase women's participation in the mapping process, which was particularly low in Chad and Sierra Leone.

5.5. Versatility

It was shown that SmartLandMaps can be applied in different contexts with an adapted community mapping process, depending on different tenure systems, community structures, and visibility of boundaries. Where boundaries are poorly visible and the participatory mapping process alone cannot produce reliable sketches on the orthophoto, a combination with additional ground measurements where necessary can be considered. Easily identifiable labels allow for the merging of non-spatial data with spatial units. In the future, different colors for the labels can even allow for different layers of information on one map.

6. Discussion

SmartLandMaps emphasizes the importance of community participation and co-creation of information, all while ensuring that the approach does not compromise on the need for digital data handling realized through a semi-automated digitization pipeline. Introducing the SmartLandMaps approach to the existing set of land tenure recording tools can be a significant step forward, especially when we consider the general benefits highlighted in Rambaldi's work on participatory GIS (PGIS) [58].

6.1. Key Takeaways

We now revisit the three research questions mentioned at the outset of the article and summarize the main lessons learned.

How to facilitate scalable land rights recording? A participatory mapping approach, combined with efficient digitization techniques can be useful for general boundary recording in a time-efficient manner. The digitization of the maps is fast (see Section 5.1), which means that the bottleneck of the approach is the effort needed to mobilize the participants and run several mapping campaigns in parallel. It should be noted that, even though the mapping sessions were carried out at different locations, contexts, and cultures, the printed orthophoto was always the key instrument for interaction, cohesion, and consensual spatial decision-making. In this sense, one could argue that the process was as important as the result, as observed in other studies as well [59]. Moreover, it was observed that SmartLandMaps has relatively low requirements when it comes to technological know-how, making it accessible and easily adopted by local entities. It only requires a minimal amount of training for local community members to become proficient in its use. In this vein, a train-the-trainers approach can easily be applied to keep the knowledge in the country [24].

How to automatically extract parcel boundaries from hand-drawn sketches? We have tested several techniques for boundary detection and boundary vectorization during the work. Table 3 shows good results for our digitization approach. Blurring as a preprocessing technique yields slight improvements in comparison to mean-shift for the detection task. For vectorization, Douglas–Peucker has often led to better results than the use of convex hulls. The two machine-learning models tested did not always yield performance as good as the algorithm for boundary extraction proposed. Since the prediction at the patch level was good (Figure 6), this is an indication that more post-processing is needed to close gaps between predicted boundaries at the patch level when reconstructing the final image. We defer a closer look into this to future work.

How to automatically extract labels from hand-drawn sketches? We have used a workflow including the printing of numbers on stickers that are placed on the paper map, a self-written script that uses OpenCV to search for stickers in the digitized map image and Tesseract for character recognition with promising results (Table 3). Early tests using hand-written digits without a symbol to mark the end of numbers, as shown in Figure 4, produced less reliable results.

6.2. Limitations

The digitization of cadastral boundaries introduces positional error as documented in Ref. [60]. In our case, these positional errors related to the boundaries may come from the different thicknesses of the lines drawn by participants and also the fact that their drawing may not perfectly align with the outlines of the boundaries on the ground. We have documented an assessment of the positional accuracy of the approach in Ref. [13]. The SmartLandMaps approach is useful for first-time recording to get an inventory of the parcels available in a region, as well as their general outlines (i.e., the general-boundary approach). It can be followed by more rigorous surveying approaches (i.e., the fixed-boundary approach) to increase the accuracy of the positions of the boundaries in the digital land administration systems.

6.3. Future Work

The SmartLandMaps approach as discussed in this manuscript presents a novel procedure to easily digitize sketched and annotated maps. However, the process of community mapping can also disadvantage minorities and exacerbate social imbalances if special attention is not given to it from the outset. As this paper aimed at a proof of concept of the technology and mapping methodology, this aspect was not the subject of this investigation and could be taken up in subsequent studies, i.e., how to ensure that all individuals and not only elites participate in the mapping session. As for the digitization, the results have shown promising results and could be extended in at least three ways. First, edge detection relied primarily on canny edge detection in this work. It would be interesting to explore alternative edge detection mechanisms (e.g., L-CNN [39]) and their impact on the results. Second, the tested machine learning-based approaches have shown promise, despite the limited training data used. This suggests that, with more data and empirical testing, we may arrive at models with even better results than those observed in this study in the future. In particular, it would be interesting to explore how U-Net and SegFormer will perform with more training data and/or data augmentation, and how additional models for semantic segmentation (e.g., TransUnet [61], UnetFormer [62]) would contribute to the automatic extraction of cadastral boundaries in future work. Third, more data in additional scenarios would be useful to increase the diversity of the data collected and increase the generalizability of the results to various types of participatory mapping contexts.

7. Conclusions

Millions of formal and informal land rights are still undocumented worldwide and there is a need for scalable techniques to facilitate that documentation. Through the combined use of satellite or drone-based aerial photography, participatory mapping, and digitization software, the SmartLandMaps approach reduces the time and costs to create digital data with information on the extent of a land right (parcel boundaries), the land rights, restrictions and responsibilities, as well as information on the land right holder. This article has presented an overview of the different components of the approach and lessons learned from its deployment in four scenarios. The SmartLandMaps approach proved to be efficient, with digitization being a reliable and quick step, in contrast to previous workflows where the proper digitization of paper sketch maps was a major bottleneck and often prone to errors. The importance of community interaction and the mapping process itself was emphasized, with the printed orthophoto being a key tool for interaction and decision-making for all community members during the mapping sessions. The SmartLandMaps approach was also accessible and easily adopted by local entities, requiring minimal technological know-how and offering the potential for a train-the-trainers approach to maintaining local knowledge. In order to automatically extract parcel boundaries from hand-drawn sketches, several techniques were tested. Blurring as a preprocessing technique gave slight improvements, and Douglas–Peucker generally outperformed convex hulls for vectorizing. The machine learning models did not consistently perform as well as the proposed algorithm for the extraction of the boundaries. The identification of labels from hand-drawn sketches was achieved by innovative character recognition modules automatically reading printed number labels placed on paper maps. All in all, the approach is most suitable for areas where inventory work will help collect basic information about land tenure/use but is less suitable for areas where the cadastre is already established at a satisfactory level.

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Notes

1 An important aspect of treating the data responsibly is *reporting*: Since the data collected is sensitive, we make sure in the reporting of the results (e.g., this article) not to display them on a digital map, as they can provide the geographic context of digitized data (and potentially lead to the identification of some participants).

2 https://getodk.org/, accessed on 31 July 2023.

3 https://www.digitalocean.com/, accessed on 31 July 2023.

4 https://www.opendronemap.org/webodm/, accessed on 31 July 2023.

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Spatial Differentiation and Environmental Controls of Land Consolidation Effectiveness: A Remote Sensing-Based Study in Sichuan, China

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Abstract: The increasing global population is leading to a decline in cropland per person, aggravating food security challenges. The global implementation of land consolidation (LC) has created new farmland and increased productivity. LC is a critical strategy in China for ensuring food security and gaining significant government support. This article investigates the impact of LC on farmland productivity in Sichuan Province in 2020. We utilize time series remote sensing data to analyze LC's impact on farmland capacity. This study uses Sentinel and Landsat satellite data to calculate CumVI and assesses the LC project's spatiotemporal evolution. To evaluate LC's effectiveness, we create indexes for yield level and stability and employ Getis-Ord Gi* to identify spatial differentiation in LC's impact. GeoDetector and GWR examine the impact of natural factors like elevation, slope, soil organic carbon, and rainfall on the effectiveness of LC. The research results show that: (1) After the implementation of LC, 55.51% of the project areas experienced significant improvements in agricultural productivity; the average increase rate of yield level is 7.74%; and the average increase rate of yield stability is 12.40%. Overall, LC is significant for improving farmland capacity. (2) The effectiveness of LC exhibits spatial differences and correlations in different areas. The main location for high-value agglomeration of yield levels is Nanchong City, while the northern part of Guangyuan City primarily hosts low-value agglomeration areas. (3) Natural conditions influence LC's effectiveness. In terms of affecting the yield level of LC, the driving factors from high to low are SOC, elevation, slope, and rainfall. In terms of affecting the yield stability of LC, the driving factors, from high to low, are elevation, SOC, slope, and rainfall. LC's effectiveness is influenced by different natural conditions that have different effects.

Keywords: land consolidation; agricultural productivity; natural attribution; Sichuan

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1. Introduction

As the global population continues to grow, the demand for food continues to grow, and the number of people at risk of hunger will also continue to increase during the same period [1]. Food security is related to overall national economic and social development, an essential cornerstone of national security [2]. Cropland resources are the most critical material conditions for agricultural production. Changes in quantity and quality will inevitably affect food production fluctuations, affecting adequate supply and food security [3]. From 2003 to 2019, global cropland expansion accelerated, and the cropland area increased by 9%. However, due to population growth, the global per capita cropland area decreased by 10% [4]. To address the above problems, countries worldwide are actively carrying out land consolidation work [5] to increase productivity by reclaiming new land and improving existing farmland's farming conditions and environment.

Land consolidation (LC) refers to the activities of adjusting and reforming the land use situation, increasing the area of effective arable land, improving the quality and utilization efficiency of land, and improving the production, living conditions, and ecological environment in a particular area [6]. It uses administrative, economic, legal, and engineering techniques following land use planning requirements. LC plays an important role that cannot be underestimated in achieving a balance of cropland [7], ensuring national food security [8], and achieving rural revitalization [9]. The term "Land consolidation" was first proposed in Germany in 1343 [10], and the "Land consolidation law" was officially promulgated in 1953 [11]. Russia and France also conducted LC work as early as the 17th and 18th centuries [12]. China is a developing country with a large population. Under the situation of a large number of arable land resources, a small relative amount per capita, limited reserve arable land, and continuous growth of non-agricultural land occupation [13], the reverse development of cropland and population has caused a sharp decline in the level of cropland per capita. Cropland has become an increasingly scarce resource and even a vital restriction for the sustainable development of agriculture [14]. Therefore, cropland resources, as the fundamental guarantee for people's lives, have received significant attention from the state and government. China has continued to increase LC efforts to ensure the red line of cropland and improve the quantity and quality of cropland [15]. During the 13th Five-Year Plan period (2016–2020), nearly 1.7 trillion yuan was invested to replenish 20 million acres of cropland, and remarkable results were achieved. However, there has been a lack of systematic and comprehensive research on the spatial differences and temporal persistence of the effectiveness of LC. Therefore, how to evaluate the impact of LC projects on farmland capacity has increasingly become the focus of social attention [16].

At present, many related studies have been carried out on how to evaluate the impact of LC on farmland capacity. In terms of research methods, farmers' surveys [17], mathematical analysis [18], potential models [19], and other techniques are mainly used. However, they are mostly limited by the survey area, survey objects, and statistical difficulty, and the accuracy of the analysis results is complex to guarantee. With the development of remote sensing data and GEE platforms, remote sensing technology has been widely used in the identification of abandoned farmland [20], agricultural crop extraction [21], and mining area monitoring [22]. It has recently become a popular technical means to identify land and finished capacity changes. Among them, the normalized vegetation index (NDVI) has an almost linear relationship with fAPAR (the proportion of absorbed photosynthetically active radiation), so it can be easily used as an indirect measure of primary productivity [23], and can eliminate the influence of topography and community structure. Shadow and radiation interference weaken the noise caused by the sun's altitude angle and the atmosphere [24] and are widely used in ecological environment changes, land use changes, crop yield monitoring, etc. Paul C used the Normalized Difference Vegetation Index (NDVI) to conduct large-area yield monitoring of wheat crops in North Dakota and South Dakota and concluded that the AVHRR NDVI shows excellent promise in predicting crop yields [25]. Fan et al. proposed a method based on the SVM algorithm to construct a time series calculation of the MODIS NDVI to characterize the four characteristic parameters of productivity level, productivity fluctuation, productivity potential, and multiple cropping index changes [26]. Regarding research data, the MODIS satellite is mainly used to obtain NDVI data to carry out research. For example, Du et al. used the NDVI data obtained by the MODIS satellite to calculate the yield changes before and after LC [27]. At the research scale, most of them start with a single research area and city- and county-level units. For example, Hong et al. used the net primary productivity (NPP), the normal difference vegetation index (NDVI), and the multi-band drought index (MBDI) to study the attributes of agricultural production after LC at a certain site in China [28]; Zhang et al. used the terrain-improved CASA model to extract the NPP index and measure the cropland capacity of Binyang County [29]. However, there is a problem in existing research: the spatial resolution of remote sensing data could be higher. For areas with complex topography such as mountains and hills, because the farmland in these areas is fragmented and most of them are highly mosaic compared to forestland, the resolution of MODIS or its derivatives is 250 m. The problem of mixed pixels under the rate is serious; there are limitations in the research scale, most evaluations are based on a specific remediation project area, and there is a lack of research on a broader scale; at the same time, existing studies lack evaluation of time continuity, and most of them are based on time nodes; in addition, most studies only focus on the effectiveness of remediation and lack a systematic analysis of factors affecting the effectiveness of remediation.

This article utilizes the 2020 LC project area in Sichuan Province as a case study, employing time series remote sensing data to examine the impact of LC on farmland capacity. Firstly, we combined the Sentinel and Landsat satellites, which can reach higher-precision spatial resolution while maintaining observation frequency, making them better suited to the study area's topography and geomorphology. Then, the integral algorithm was used to calculate CumVI, and the data from the three years before and after the collation were analyzed for temporal changes; secondly, we constructed two indices of yield level and yield stability to assess LC projects' effectiveness and spatiotemporal evolution characteristics. On this basis, we studied the spatial differentiation of LC effectiveness using Getis-Ord Gi* characteristics; finally, we employed spatial quantitative analysis to investigate the impact of the four natural elements of elevation, slope, SOC, and rainfall on LC productivity.

2. Materials and Methods

2.1. Study Area

As the economic development center of southwest China, Sichuan Province is an integral part of the national development strategy. It is also one of the 13 central grain-producing provinces in the country and the only central grain-producing province in the west. In 2020, Sichuan's grain yield ranked 9th in the country. As shown in Figure 1, Sichuan Province is located between 26°03′–34°19′ north latitude and 97°21′–108°12′ east longitude. It is inland in southwest China and the upper reaches of the Yangtze River. Sichuan Province is located on the first and second levels of the three significant terrain ladders in China's mainland, that is, in the transition zone between the first-level Qinghai-Tibet Plateau and the second-level plain source of the middle and lower reaches of the Yangtze River [30]. There is a significant difference between the east and west; the terrain is high in the west and low in the east. Sichuan's landforms are complex, with mountains as the main feature, and there are four landform types: mountains, hills, plains, and plateaus. The climate of the Sichuan Province is also very different. In the Sichuan Basin, the eastern part has a humid subtropical climate; the southwest has a mountainous semi-humid climate; and the northwest has an alpine and plateau alpine climate. Sichuan Province's topographic characteristics and climate conditions primarily distribute its agricultural planting areas in the eastern basin, with rice, corn, and wheat being the most commonly grown crops. In recent years, problems such as non-grain conversion of cropland, cropland abandonment, and farmland fragmentation have gradually intensified, posing a threat to the food security of Sichuan Province. At the same time, Sichuan Province is also actively carrying out LC projects. In the latest round of comprehensive LC planning (2016–2020), Sichuan Province has implemented a total of 1581 land development and consolidation projects, adding 68,200 hectares of cropland; the infrastructure conditions for agricultural production have been improved, referred to as high-standard farmland, with 107,900 hectares. Grain production has increased by 66,190 kg due to the improved cropland quality, and both the area and quality of cropland have significantly improved.

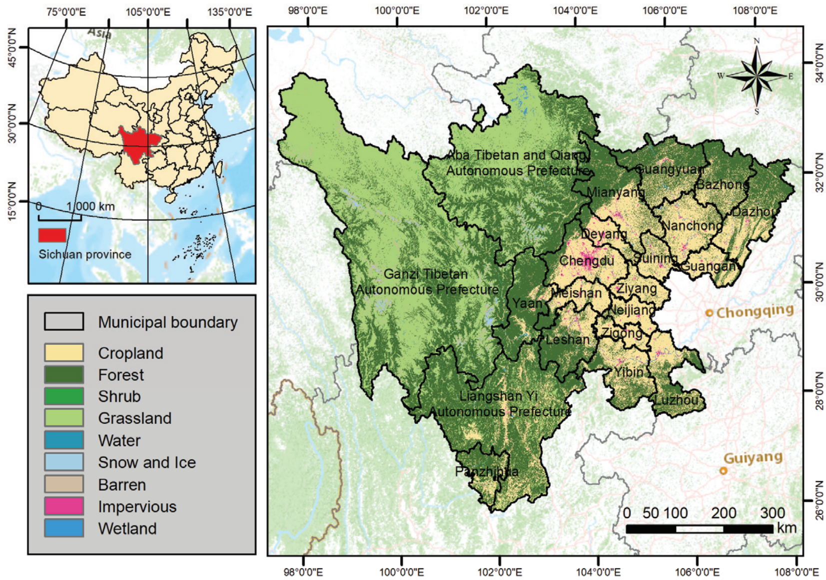

Figure 1. Overview of the study area.

2.2. Sources of Data

The data used in this paper mainly include remote sensing data, project area data, and other dataset products, and the specific data information and sources are shown in Table 1.

Table 1. Information and sources of data.

Data	Classification	Resolution	Time	Data Source
Landsat 8	raster	30 m	2017–2024	https://www.usgs.gov (accessed on 12 December 2023)
Sentinel-2	raster	10 m	2017–2024	https://www.esa.int (accessed on 12 December 2023)
LC project	vector	/	2020	Sichuan Provincial Government (accessed on 5 March 2022)
DEM	raster	30 m	2022	https://panda.copernicus.eu/panda (accessed on 3 January 2024)
SOC	raster	250 m	1950–2017	https://data.isric.org/geonetwork (accessed on 3 January 2024)
Rainfall	raster	1 km	2020	https://www.gis5g.com (accessed on 3 January 2024)

"/" indicates that the data does not have the relevant attribute.

2.2.1. LC Project Data

The project area data used in this article come from the Sichuan Province LC project database, which contains approximately 5800 LC projects in Sichuan Province from 1999 to 2020. The data include project number, name, category, administrative region, acceptance date, total project investment, and other information. It should be noted that due to the limitation of the number of effective observations of the selected satellites, the number of effective observations in 2016 was significantly higher than that in 2015, with a median of more than 24 times, which can ensure the fidelity of the time series, so we selected the time period after 2016 as the optional research time period. At the same time, to ensure that the number of years before and after LC is at least three years and consistent, we selected 227 LC projects with the project date "2020" and used 2017 to 2024 as the specific research time period. All LC projects were completed and accepted in 2020.

2.2.2. Sentinel-2 A/B and Landsat 8

To solve the problem that a single MODIS satellite is not suitable in areas with complex topography, such as mountains and hills, we combined Landsat 8 OLI and Sentinel-2A/B MSI, and their data processing level is the top of the atmosphere (TOA). Landsat8 OLI is provided by NASA and the United States Geological Survey (USGS), and Sentinel-2 MSI is provided by the European Space Agency (ESA). Among them, Landsat 8 was launched in 2013, with a spatial resolution of 30 m and a revisit period of 16 days; the Sentinel-2A/B binary stars were launched in 2015 and 2017, respectively, with a maximum spatial resolution of 10 m, the double star revisit period is once every five days.

2.2.3. Geospatial Data

The elevation data used in this study are the 2022 Copernicus DEM data with a spatial resolution of 30 m, released by the European Space Agency (https://panda.copernicus.eu/panda (accessed on 3 January 2024)); the precipitation data come from the development of the Earth Resources Data Cloud Platform China's 1 km resolution annual average rainfall dataset (https://www.gis5g.com (accessed on 3 January 2024)), which is obtained by interpolation based on data from 2472 meteorological observation points across the country; soil organic carbon content data were produced by Professor Tomislav Hengl (https://data.isric.org/geonetwork (accessed on 3 January 2024)), the data are based on a compilation of global soil profiles and samples from 1950 to 2017 obtained by using R language machine learning, with a spatial resolution of 250 m.

2.3. Research Methods

The overall technical framework for identifying LC capacity changes and analyzing effect attribution is shown in Figure 2. The workflow mainly includes four essential steps. First, we used multi-source remote sensing data Landsat 8 and Sentinel-2 A/B, which were normalized, cloud masked, and S-G filtered to obtain NDVI time series at 10-day intervals, and computed annual CumVI using an integration algorithm to characterize annual cropland yield; secondly, we proposed a characteristic parameter method to identify changes in productivity to identify changes in yield level and yield stability before and after LC, and divided the effectiveness of LC into four types type; then, we used the hotspot analysis method to explore the spatial differentiation of LC effectiveness; finally, based on four natural condition factors, we obtained the average value of each project area through zoning statistics, and used GeoDetector and GWR to analyze the impact of natural conditions on the effectiveness of LC.

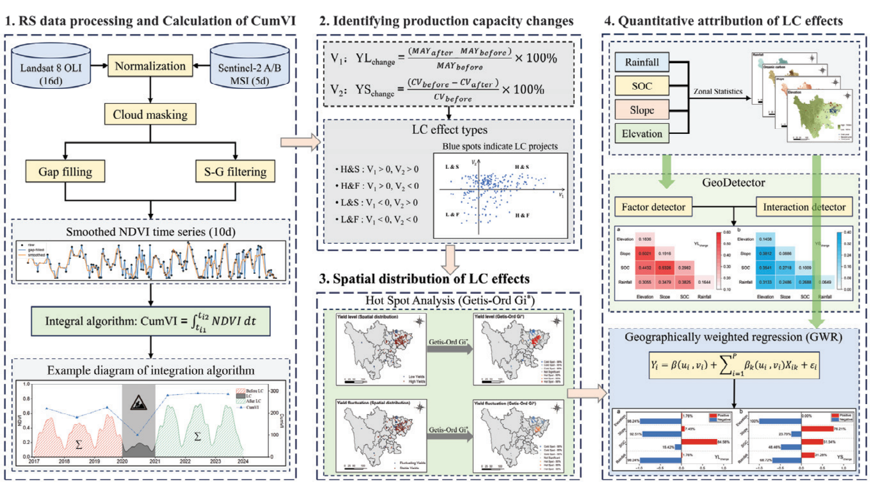

Figure 2. Technology roadmap framework.

2.3.1. Remote Sensing Data Processing and CumVI Calculation

Due to the differences in spectrum and reflectance between OLI and MSI, they must be coordinated to obtain stackable results. Zhang et al. proposed a method using ordinary least squares (OLS) linear regression to normalize the two sensors, improve the consistency between Sentinel-2A MSI and Landsat-8 OLI data, and obtain a higher degree of fitting [31]. Based on this method, we normalized the NDVI calculated by Landsat-8 to the NDVI of Sentinel-2 A/B to reduce the NDVI difference caused by factors such as satellite spectral response functions. The quality band was combined with satellite data to reduce cloud contamination and oversaturation. Then, we used the maximum value synthesis approach to generate a ten-day time series for the non-uniformly collected NDVI data. We utilized a linear function to fill in the missing values in the middle, followed by the SG filter technique to smooth and erase the NDVI pixels. After considering the influence of residual clouds, haze, and other factors, we obtained the NDVI time series evenly sampled at 10-day intervals.

Johnson et al. used the MODIS NDVI to evaluate corn and soybean yields in the United States. The results showed that corn and soybean yields positively correlate with the NDVI [32]. Therefore, we calculated the integral sum of the smoothed NDVI time series by year to obtain CumVI. The total annual yield can be characterized, and the formula is as follows:

$$\text{CumVI} = \int_{t_{i1}}^{t_{i2}} \text{NDVI}\, dt \tag{1}$$

In the formula, the NDVI is the value after SG filtering, and t_{i1} and t_{i2} are the starting and ending times of the *i*-th year time series, respectively.

2.3.2. Characteristic Parameter Method to Identify Production Capacity Changes

LC improves farmland farming conditions and the environment for agricultural production through comprehensive consolidation and optimized allocation. Existing studies generally believe LC can effectively improve agricultural production capacity to ensure food security and increase farmers' income [33,34]. In an ideal world, the impact of LC on productivity can be reflected in two aspects: an increase in yield level due to improved farming conditions and an increase in inter-annual yield stability. Therefore, we used two indicators to evaluate the effect of LC: the first V_1 is the change rate of yield level before and after LC (YL_{change}), and the second V_2 is the change rate of yield stability before and after LC (YS_{change}). The calculation formulas are as follows Equations (2) and (3), where the mean annual yields before and after consolidation ($MAY_{before/after}$) are the annual CumVI before and after consolidation, and the coefficient of variation before and after consolidation ($CV_{before/after}$) are the standard deviation of annual CumVI before and after consolidation.

$$V_1: \ YL_{change} = \frac{(MAY_{after} - MAY_{before})}{MAY_{before}} \times 100\% \tag{2}$$

$$V_2: \ YS_{change} = \frac{(CV_{before} - CV_{after})}{CV_{before}} \times 100\% \tag{3}$$

Therefore, when $V_1 > 0$, it means that LC is efficacious in improving yield level, and the average annual yield after LC increases; when $V_2 > 0$, it means that LC is efficacious in improving yield stability, the inter-annual yield volatility after LC is reduced and the stability is improved. As shown in Table 2, we can divide the LC effect into four types: high and stable yield (H and S), high and Fluctuating yield (H and F), low and stable yield (L and S), and low and fluctuating yield (L and F).

Table 2. Classification of LC effects and interpretation of indicators.

	H and S	H and F	L and S	L and F
Full name	High and stable yield	High and fluctuating yield	Low and stable yield	Low and fluctuating yield
Index	$V_1 > 0, V_2 > 0$	$V_1 > 0, V_2 < 0$	$V_1 < 0, V_2 > 0$	$V_1 < 0, V_2 < 0$

2.3.3. Research on the Spatial Distribution of LC Effectiveness

Based on ArcGIS, this study conducted a hotspot analysis (Getis-Ord Gi*) on the LC effectiveness (YL_{change} and YS_{change}) to explore its spatial cluster characteristics. The Getis-Ord Gi* index is mainly used to detect space aggregation. The core idea is to calculate the local sum of an element and its neighboring elements within a given distance compared to the sum of all elements. It is used to analyze the degree of clustering of attribute values at the local spatial level [35]. The formula is:

$$Gi^* = \frac{\sum_{j=1}^{n} W_{ij}(d)X_j}{\sum_{j=1}^{n} X_j} \quad (4)$$

Among them, X_j is the attribute value of element j, W_{ij} is the spatial weight between elements i and j, and n is the total number of elements. The statistical test of the Getis-Ord Gi* statistic can be expressed according to the corresponding standardized form (Z value), as expressed in Equation (5):

$$Z(Gi^*) = \frac{\sum_{j=1}^{n} W_{ij}X_j - \overline{X}\sum_{j=1}^{n} W_{ij}}{\sqrt{\frac{\sum_{j=1}^{n} X_j^2}{n} - \left(\overline{X}\right)^2}\sqrt{\frac{\left[n\sum_{j=1}^{n} W_{ij}^2 - \left(\sum_{j=1}^{n} W_{ij}\right)^2\right]}{n-1}}} \quad (5)$$

When the value of Z is greater than 0, it indicates high-value spatial agglomeration, and the larger the value of Z is, the more significant the agglomeration is; when the value of Z is less than 0, it indicates low-value spatial agglomeration, and the smaller the value of Z is, the more significant the agglomeration is; when the value of Z is equal to 0, it indicates that the agglomeration is not substantial.

2.3.4. Quantitative Attribution of Natural Factors for LC Effectiveness

(1) GeoDetector

GeoDetector is a set of statistical methods that detect spatial differentiation and reveal the driving forces behind it [36]. The rationale is that when the spatial distributions of the explanatory and explanatory variables are more similar, the effect of the explanatory variable on the explanatory variable is more significant [37]. The formula is shown in (6):

$$q = 1 - \frac{1}{N\sigma^2}\sum_{h=1}^{L} N_h\sigma_h^2 \quad (6)$$

In the formula, the value of "q" represents the index of the spatial differentiation of the influence of the four types of natural condition factors on the effect of LC, and the more significant the value, the greater the impact; "h = 1, 2 . . . L" is the classification of the four types of natural condition factors; "N_h" and "N" are the number of units in the h-level region and the entire region, respectively; "σ^2" and "σ_h^2" are the variance of the LC effectiveness for the whole area and the area at level "h", respectively.

In addition, we used GeoDetector to detect the interaction of four natural condition factors to determine whether the explanatory power of the dependent variable is enhanced or weakened when two influences act together, or whether the effects of these factors on the dependent variable are independent of each other [36]. The following five situations will occur after the interaction of two factors:

Nonlinear weakening: $q(X_1 \cap X_2) < \min(q(X_1), q(X_2))$;

Single factor nonlinear weakening: min ($q(X_1)$, $q(X_2)$) <$q(X_1 \cap X_2)$ < max($q(X_1)$, $q(X_2)$);
Two-factor enhancement: max($q(X_1)$, $q(X_2)$) < $q(X_1 \cap X_2)$ < $q(X_1)$ + $q(X_2)$;
Independent: $q(X_1 \cap X_2)$ = $q(X_1)$ + $q(X_2)$;
Nonlinear enhancement: $q(X_1 \cap X_2)$ > $q(X_1)$ + $q(X_2)$;
Among them, $q(X_1 \cap X_2)$ represents the maximum effect of X_1 and X_2; $q(X_1)$ + $q(X_2)$ represents the sum of the effects of X_1 and X_2.
(2) Geographically weighted regression (GWR)
Traditional linear regression models (OLS models) only estimate all samples and parameters globally and do not incorporate the consideration of elements such as spatial patterns [38]. GWR is solved through a local weighted regression analysis model about the position and uses parameter estimation results that change with different spatial positions to quantitatively reflect the heterogeneity or non-stationary characteristics in the spatial data relationship [39]. Therefore, we used the GWR model to perform the analysis. We compared the parameters of OLS and GWR in the follow-up results to verify the suitability of the GWR model. The formula is as shown in Equation (7) Show:

$$Y_i = \beta_0(u_i, v_i) + \sum_{i=1}^{P} \beta_k(u_i, v_i) X_{ik} + \varepsilon_i \quad (7)$$

Y_i represents the value of the dependent variable at position i; X_{ik} is the value of the independent variable k at position; $\beta_k(u_i, v_i)$ and $\beta_0(u_i, v_i)$ are, respectively, the coefficients and intercepts of the regression model established by GWR at position i, P represents the number of predictor variables; ε_i is the regression residual of point i; (u_i, v_i) represents the spatial position of point i.

3. Results

3.1. Typical Processes and Characteristics of LC Effectiveness

As shown in Figure 3a, this article listed NDVI time series diagrams of four typical project areas to represent the productivity changes in the above four LC effects. Among them, "Gap-filled" represents the NDVI curve obtained by linear filling of the original measurement data, and "Smoothed" represents the NDVI curve after S-G smoothing. The table on the correct records the names of four typical project areas and the values of CumVI, YL_{change}, and YS_{change} indicators each year before and after LC. The NDVI time series curve is similar to the trend of a sinusoidal function. In each annual period, the NDVI first has an upward trend, which is caused by the growth and development of crops; when reaching a specific peak value, the NDVI begins to decrease, which is caused by harvesting. In addition, different types of LC effects also have different NDVI time series curves. For example, the "LC project in Panlong Township, Nanbu County": before LC (2017–2020), the total annual yield of farmland remained at a low level (CumVI < 0.3), with inter-annual fluctuations also relatively large; during the LC stage (2020–2021), since project implementation makes a certain degree of intervention on the land, the NDVI will further decline, and it will take some time to return to a higher and stable level; when the LC project is completed (after 2021), agricultural production capacity will return to a high and stable level (CumVI > 0.3).

As shown in Figure 3b, among the 227 LC projects in Sichuan Province in 2020 selected in this study, the average value of V_1 is 7.74%, the maximum value is 47.91%, and the minimum value is −17.60%, indicating that some project areas have decreased yield levels after LC; the average value of V_2 is 12.40%, the maximum value is 95.44%, and the minimum value is −201.35%, indicating that some project areas have decreased yield stability after LC.

As shown in Figure 3c, a total of 126 project areas have achieved increased yield level and improved stability, accounting for 55.51% of the total number of project areas; 45 project areas have increased yield level but decreased stability, and 26 project areas have decreased yield level but increased stability, which together account for 31.27% of the total number of project areas; a total of 30 project areas, or 13.22% of the total number of project areas, had declining yield level and decreased stability.

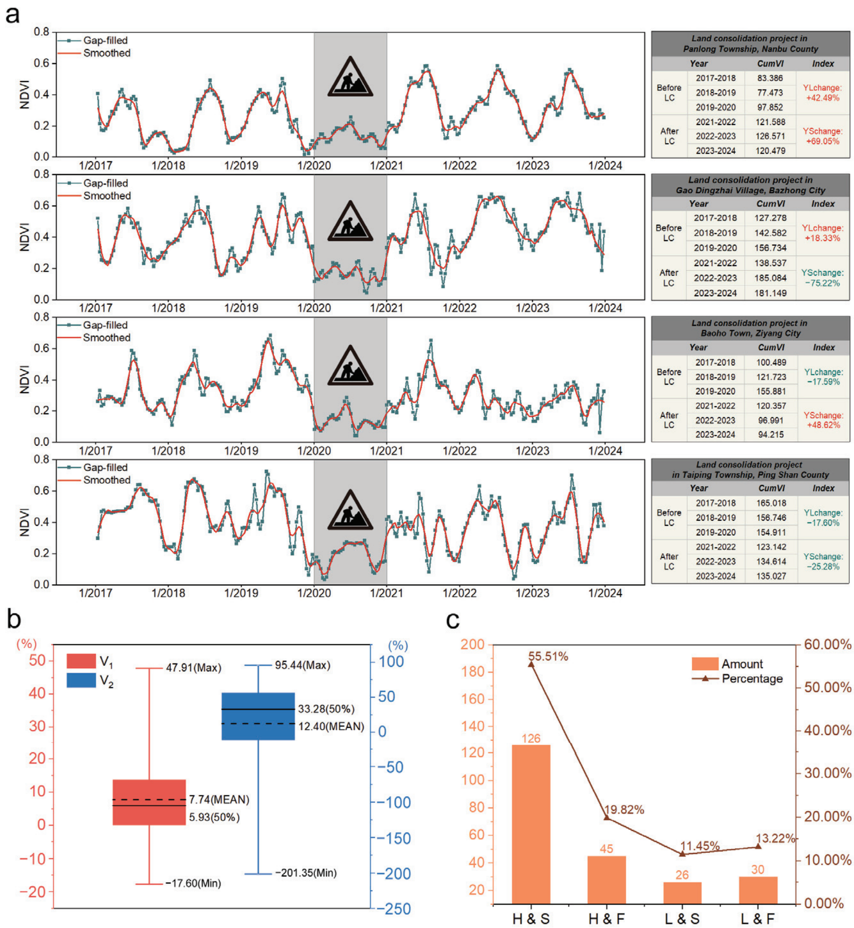

Figure 3. Typical process and characteristics of LC on cropland productivity enhancement. (**a**) NDVI time series diagram of the typical project with four types of productivity changes; (**b**) statistics on YL_{change} (V_1) and YS_{change} (V_2) of the consolidation projects; (**c**) statistics on the number and proportion of projects with different effects.

In summary, the 2020 LC project in Sichuan Province effectively enhanced yield level and stability. The average improvement rates of the two are 7.74% and 12.40%, respectively. Over half of the project area has achieved the dual effect of increasing and stabilizing production. However, after implementing LC projects, production capacity regression in some project areas remains a problem.

3.2. Spatial Distribution of LC Effectiveness

We explored the characteristics of the spatial distribution of YL_{change} and YS_{change} and analyzed their spatial correlation using Getis-Ord Gi*. Figure 3 shows that the 2020 LC project areas in Sichuan Province are mainly distributed in the northeastern region, with most of them in Nanchong City, Guangyuan City, Bazhong City, and Dazhou City. Scattered project areas in central and southern Sichuan Province are distributed in Ya'an City, Meishan City, Ziyang City, Yibin City, and Liangshan Yi Autonomous Prefecture.

From Figure 4a,c, it can be seen that the project areas realizing yield level improvement in 2020 are mainly distributed in Nanchong City and its surrounding areas and show a centralized and contiguous distribution; the project areas with reduced yield level, on the other hand, are mainly located in the northern part of Guangyuan City, the northwestern and southeastern parts of Mianyang City, the Liangshan Yi Autonomous Prefecture, and the Ganzi Tibetan Autonomous Prefecture, showing a more discrete distribution pattern. The Getis-Ord Gi* analysis shows that the high values of yield level increase are distributed in Nanchong City with a 99% confidence level, and the low values are mainly distributed in the northern part of Guangyuan City with a 99% confidence level, which indicates that the spatial distributions of both high and low values of yield level are correlated, and the clustering of high values is more significant.

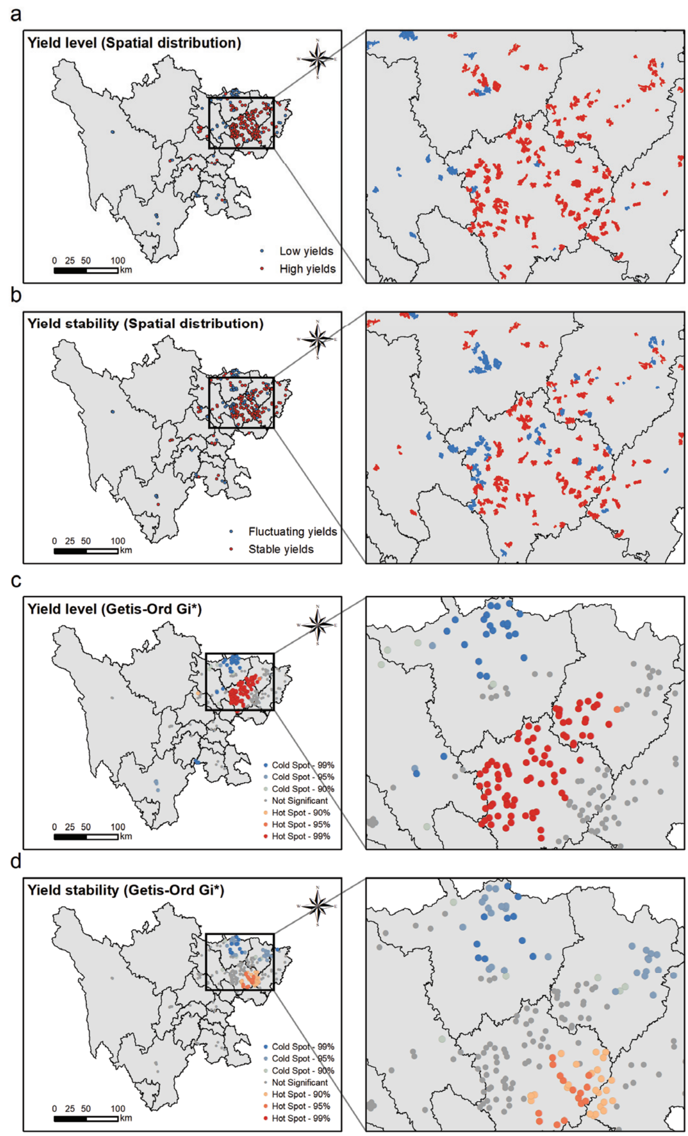

Figure 4. Spatial distribution of yield variation characteristics. (**a**) Spatial distribution of yield level; (**b**) yield level Getis-Ord Gi* analysis; (**c**) spatial distribution of yield stability; (**d**) yield stability Getis-Ord Gi* analysis.

It can be seen from Figure 4b,d that the project areas with increased yield stability are mainly located in Nanchong City, with discrete distribution in Mianyang City, Bazhong City, and Dazhou City, while the project areas with decreased yield stability are mainly located in the northern part of Guangyuan City, with distribution in the western part of Nanchong City and Bazhong City. It is worth noting that the results of the Getis-Ord Gi* analysis of yield stability show that high-value agglomerations are distributed only in the southwestern part of Nanchong City, and the confidence level is lower than 99%; low-value agglomerations are mainly distributed in the northern part of Guangyuan City and the eastern part of Bazhong City, etc., with a confidence level of 95%, which indicates that the spatial distributions of high and low values of yield stability are equally correlated, but the significance level of the distribution of the correlation of the latter is lower compared the former.

3.3. Natural Attribution of LC Effectiveness Based on GeoDetector

To study the factors influencing the effectiveness of LC, this study selected four types of natural condition factors: elevation, slope, soil organic carbon (SOC), and rainfall. Elevation and slope can mirror the intricacy of the topographic conditions in the project area; soil organic carbon (SOC) is a crucial component of soil, considered the core of soil quality and function [40], and a decisive factor influencing soil fertility [41]. Water also plays a significant role in crop growth [42], while rainfall reflects the water environment in the project area. We used the "nature breaks" method to divide the four types of natural conditions into five levels. Then, we utilized GeoDetector to analyze the degree of influence and interaction of factors on LC effectiveness.

As shown in Table 3, in the results of GeoDetector's factor detection: "factors" enumerate four different natural condition factors; the q-value measures the extent to which factor X explains the spatial differentiation of attribute Y, that is the degree of influence on the LC effect; the *p*-value represents the significance test result of the q value, and all factors passed the significance test. The result of the q value of YL_{change} is SOC (0.2982) > slope (0.1916) > elevation (0.1836) > rainfall (0.1644). It can be seen that SOC is the most critical influence on YL_{change}, with slope, elevation and rainfall remaining in that order. The q-value result of YS_{change} is elevation (0.1458) > SOC (0.1009) > slope (0.0885) > rainfall (0.0649). It can be seen that elevation is the most critical influence on YS_{change}, with SOC, slope, and rainfall remaining in that order.

Table 3. LC effect divergence and factor detection.

Factors	**YL_{change}**			**YS_{change}**		
	q	**p**		**q**	**p**	
Elevation	0.1836	0.000	3	0.1458	0.011	1
Slope	0.1916	0.000	2	0.0886	0.000	3
SOC	0.2982	0.000	1	0.1009	0.007	2
Rainfall	0.1644	0.000	4	0.0649	0.048	4

As shown in Figure 5a, in the results of GeoDetector interaction detection, six interaction categories exist among the four types of natural condition factors. All interactions of both two factors on the spatial differentiation of land preparation yield levels are greater than the effect of either variable alone; in particular, interactions of slope∩SOC and elevation∩slope are greater than the independent sum of the two, which are nonlinearly augmented, while the interactions of the remaining factors are two-way augmented; moreover, the interaction effects of slope∩SOC and elevation∩slope are significant, and the q value is greater than 0.5. As shown in Figure 5b, among the interactions on YS_{change}, all interactions between two factors on the spatial differentiation of LC yield stability are greater than the effect of the two independently added together; all of them are nonlinear enhancements; interactions of elevation∩slope and elevation∩SOC are more significant.

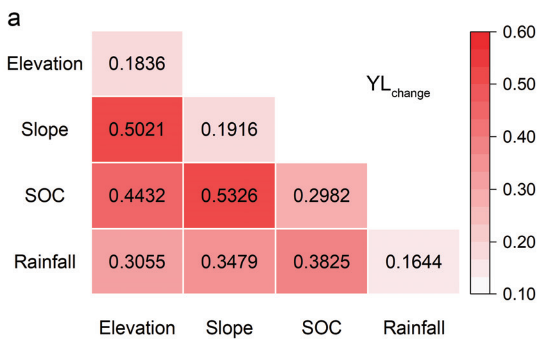

Figure 5. LC effect interaction detection: (**a**) detection of the interaction of changes in yield level; (**b**) detection of the interaction of changes in yield stability.

3.4. Natural Attribution of LC Effectiveness Based on GWR

GeoDetector can only explore the degree of influence and interaction of different factors on the LC effectiveness and cannot show the trend of influence of independent variables on dependent variables. This study used GWR to perform regression analysis on LC yield level and yield stability. It should be noted in advance that the total investment in LC projects in Sichuan Province is standardized and positively correlated with the size of the project area, so the investment amount per unit in different project areas is roughly the same, thus eliminating the impact of project investment on the effectiveness of LC projects. Table 4 compares the model parameters of OLS and GWR. It can be seen that compared with OLS, the Adj.R^2 of the GWR model is more extensive, and the AICc of the GWR model is also smaller, indicating that the GWR model has a better fitting degree.

Table 4. Parameter comparison of OLS and GWR.

	YL_{change}			YS_{change}		
Model	**R^2**	**Adj.R^2**	**AICc**	**R^2**	**Adj.R^2**	**AICc**
OLS	0.514	0.505	167.42	0.205	0.191	257.76
GWR	0.886	0.843	85.76	0.661	0.554	101.69

As shown in Figures 6a and 7, the influence trends of the four natural conditions factors on YL_{change} differ. The coefficient estimates of elevation, slope, and rainfall are mainly negative, indicating that they negatively affect the improvement of YL_{change}.The negative impact of elevation, slope, and rainfall account for 98.24%, 92.51%, and 98.24%, respectively. In addition, the intensity of impacts varies from region to region; for example, the absolute value of the rainfall coefficient gradually decreases from east to west, and the negative effect gradually weakens accordingly. For SOC, its coefficient estimate is mainly positive, indicating that SOC positively impacts the improvement of YL_{change}. The proportion of the positive effect is 84.58% and gradually weakens from south to north. However, a noteworthy negative effect of 15.42% remains, mainly distributed in areas such as Guangyuan City, Bazhong City, and the northern part of Nanchong City.

As shown in Figures 6b and 8, the influence trends of the four natural condition factors on YL_{change} are also different and more complex.The coefficient estimates for elevation are all negative, indicating that it has a single inhibitory effect on YS_{change}, with the negative effect diminishing from northeast to southwest. Slope has 76.21% positive effect and 23.79% negative effect; SOC has 51.54% positive effect and 48.46% negative effect; rainfall has 31.28% positive effect and 68.72% negative effect. It suggests that the effects of the three on YS_{change} are more complex, with more pronouncedly opposite trends across geographic locations.

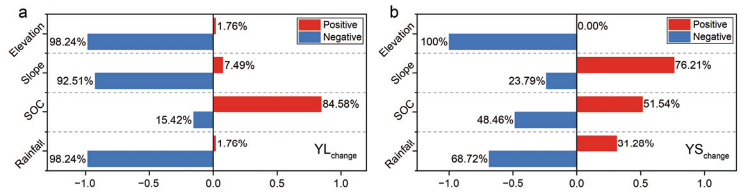

Figure 6. Proportion of positive and negative effects of different independent variables. (**a**) Proportion of positive and negative effects of YL_{change}'s impact factor; (**b**) proportion of positive and negative effects of YS_{change}'s impact factor.

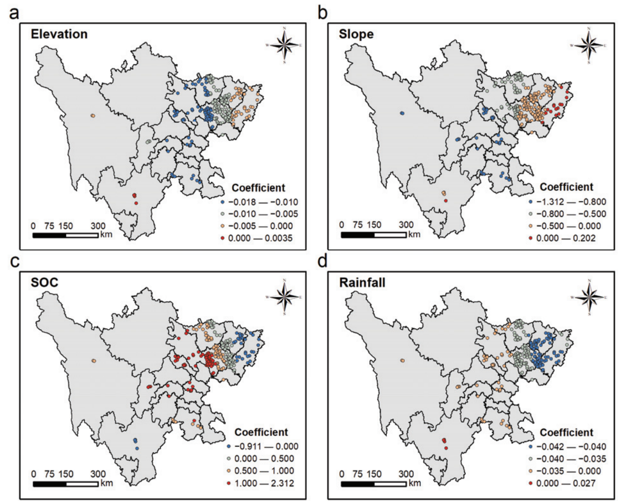

Figure 7. Spatial distribution of independent variable coefficient based on YL_{change} (**a**) Spatial distribution of coefficient of elevation; (**b**) spatial distribution of coefficient of slope; (**c**) spatial distribution of coefficient of SOC; (**d**) spatial distribution of coefficient of rainfall.

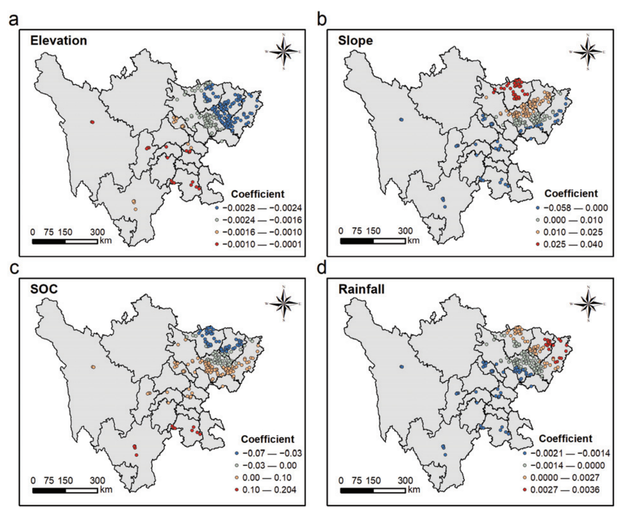

Figure 8. Spatial distribution of independent variable coefficient based on YS_{change} (**a**) Spatial distribution of coefficient of elevation; (**b**) spatial distribution of coefficient of slope; (**c**) spatial distribution of coefficient of SOC; (**d**) spatial distribution of coefficient of rainfall.

4. Discussions

4.1. Advantages and Advancements

This study used remote sensing data to analyze the productivity changes and influencing factors of the LC project area in Sichuan Province in 2020. Compared with traditional research methods, remote sensing technology has the characteristics of comprehensive coverage, long time, and high accuracy and can more accurately determine the productivity characteristics of cropland. Machine learning and deep learning algorithms have developed rapidly in recent years and have been widely used in recognizing cropland information and predicting crop yields. However, this method mainly relies on establishing the correlation between yield and characteristic variables, which greatly depends on field sampling or actual measured yield data. This study establishes a relative yield relationship, which does not depend on actual measured yield data. Therefore, it greatly reduces the cost of data acquisition and is an efficient acquisition method. However, it should also be seen that our study does not utilize the actual measured yield data, so the measured yield is not the absolute capacity of arable land. However, it has a good advantage in the field of analyzing the effect of land consolidation on the capacity of cropland. We used a combination of Sentinel and Landsat satellites to generate NDVI time series data, then used the SG filtering algorithm to fill it out smoothly. In this paper, two satellites, Sentinel and Landsat, were combined to generate NDVI time series data, filled and smoothed using the S-G filtering algorithm, followed by linear interpolation to generate 10 m spatial resolution images. This approach dramatically improves temporal and spatial accuracy and solves the problem of single MODIS satellite data not being applicable in areas with complex topography, such as mountainous hills. This paper also breaks through the limitations of traditional research at a single time node by constructing an NDVI time series before and after LC. In addition, our project area data come from Sichuan Province, so it is more precise and has a wider study scale compared to a single project area, which can explore the regularity of the effect of land consolidation differences from a more macroscopic point of view. Most of the studies on similar topics only drew on existing experience to speculate on the factors affecting land consolidation effectiveness [26], without using real data to analyze the influencing factors of land consolidation effectiveness from a quantitative perspective. In contrast, this study utilized GeoDetector and GWR models to quantitatively analyze the impacts of the four natural factors, respectively, to reveal the regularity of the influence of natural conditions on the effectiveness of LC. Therefore, this study is of a certain degree of cutting-edge and reference significance. Our results show that land consolidation can effectively improve the productivity of arable land in general, but there are still some project areas where the productivity of arable land decreases after land consolidation. Du et al. measured China's land consolidation project areas in 2006 and 2007 using NDVI data [27]. Their results showed that in 2006 and 2007, 78.67% and 78.32% of the project areas experienced either improved or stabilized productivity following the LC. However, there were also project areas where productivity declined or fluctuated. This indicates that land consolidation can enhance the productivity of arable land significantly. Their study shares similarities with our findings, providing additional support for the validity of this study.

4.2. The Impact and Inspiration of LC on Farmland Productivity

The average improvement rate of yield level of LC projects in Sichuan Province in 2020 is 7.74%, and the average improvement rate of yield stability is 12.40%; more than half of the project areas have achieved both an increase in yield level and yield stability. LC mainly improves farmland capacity through two aspects: strengthening agricultural infrastructure to support an increase in yield per unit area, or conducting land formation and field consolidation to increase planting area [27]. However, there are still problems with some projects experiencing a decrease in average annual yield or an increase in inter-annual yield fluctuations after implementing LC projects. This may be due to certain defects in the project's construction, such as irrational construction that may damage the soil layer, affecting the cropland's quality. Improper post-project management may also make it difficult to put the consolidated land into use, which may be due to the Chinese particular land ownership structure. In addition to the above, there may be certain external factors: the abandonment of cropland due to economic backwardness, poor geography, etc., may also cause a decline in cropland productivity [43]. Moreover, weather and climate are key driving factors that affect the productivity of agricultural systems [44]. Therefore, there may be a phenomenon where climatic conditions become severe after LC, resulting in a serious decline in farmland productivity, and the improvement of farmland capacity from LC cannot be effectively demonstrated.

Revealing the natural attribution of productivity changes can provide enlightenment for LC work. Regarding explaining the spatial differentiation of the LC yield level, the Adj.R^2 of the GWR model is 0.843, indicating that the four natural factors have good explanatory power on the LC yield level. SOC is the most important influencing factor, mainly showing a positive effect. This indicates that the larger the SOC, the higher the fertility potential of the soil [45], the greater the potential that can be stimulated after the implementation of LC, and therefore, the more significant the increase in yield level. Further, the interaction between elevation and slope also has a non-negligible influence. Both of them together show a negative effect. This indicates that the complexity of topographic and geomorphological conditions makes implementing and managing LC projects more difficult. For example, in the northern part of Guangyuan City and the northwestern part of Mianyang City, which are located on the northwestern edge of the Sichuan Basin, the elevations and slopes are larger, and the yield level of arable land is less elevated. On the contrary, in the central part of Nanchong City, where the elevation and slope are smaller, the yield level of arable land is higher. Rainfall mainly has a negative effect on the yield level of LC, which shows that in areas with low rainfall, LC can vastly improve the problem of water source drought in cropland and improve the yield level of cropland through measures such as building drainage ditches and improving irrigation facilities. The annual precipitation in the Sichuan Basin decreases from the periphery to the center; for example, Nanchong City and the southwestern part of Bazhong City are located in the central hilly area of the Sichuan Basin, and the annual rainfall is less than 900 mm, and the rate of improvement of the level of land consolidation yield is higher; however, the western part of Mianyang City and the eastern part of Dazhou City are located in the western and eastern rims of the Sichuan Basin, respectively, and the rainfall is generally more than 1200 mm, and the rate of improvement of the level of land consolidation yield is generally lower. In terms of explaining the spatial differentiation of LC yield stability, the R^2 of the GWR model is 0.554, indicating that the four natural factors have relatively poor explanatory power on LC yield stability. In addition, the GeoDetector interaction analysis results also show that the nonlinear enhanced interaction between two factors is much greater than the effect of a single factor. This also suggests that the effects of different factors on the stability of land consolidation yields are not independent of each other, but that there are relatively complex interactions. Elevation is the most critical factor affecting changes in the yield stability of LC, showing a single negative effect, and is the primary consideration for evaluating changes in yield stability. The influence trends of slope, SOC, and rainfall differ in different geographical locations, exhibiting apparent non-stationary effects. The impact of these three factors is relatively weak, but their interaction with other factors is significantly amplified. It also reminds us that we should consider the specific conditions of different regions and evaluate a comprehensive analysis based on various factors.

4.3. Limitations and Future Work

This study analyzed the changes in farmland capacity by comparing the annual CumVI before and after LC. Due to the limited number of effective observations by Sentinel and Landsat satellites, we only calculated the data separately for the three years before and after LC, so there may be some random errors. In addition, due to the relatively short time period across which this study was conducted, we did not take into account the interference with cropland yields caused by human factors such as cropland abandonment, transformation of agricultural land, and cropping structure adjustment, nor did we eliminate the error due to the impact of inter-annual differences in climatic conditions on crop yields. Subsequent research can improve related problems by setting up control areas and controlling variables around the study area. This article only considered natural condition factors, while social, economic, and other factors can also affect the effectiveness of LC; moreover, the specificity of the distribution of the data sample and the limitation of the number of samples can also make the regression results have some errors. Subsequent research can be carried out on a larger scale from more dimensions, such as the natural environment, social economy, and project attributes, to obtain more general and precise regularities and conclusions.

5. Conclusions

In this study, we proposed an NDVI-based method for monitoring LC effectiveness's spatial and temporal processes and characteristics in Sichuan Province. Based on the data of 227 LC project areas, we integrated Sentinel and Landsat satellites to extract NDVI data. We utilized an integration algorithm to calculate the annual yield of the project areas. We used "YL_{change}" and "YS_{change}" indexes to evaluate the effectiveness of LC. Finally, we analyzed the impacts of elevation, slope, SOC, and rainfall on the LC effectiveness using the GeoDetector and GWR model. The results show that the average improvement rate of production level in all project areas in 2020 is 7.74%, and the average improvement rate of production stability is 12.40%. Among them, 55.51% of the project areas have achieved an increase in yield and stability, 19.82% of the project areas achieved an increase in yield but a decrease in stability, 11.45% of the project areas achieved a reduction in yield but an increase in stability, 13.22% of the project areas achieved a reduction in yield and stability. Overall, LC is effective in increasing cropland's capacity. In space, the yield level and yield stability of LC have clusters of high and low values, and the spatial clustering significance of changes in yield level is more significant than changes in yield stability. In the quantitative attribution of natural factors for the effectiveness of LC, SOC and elevation are the most critical factors affecting the yield level and yield stability of LC, respectively. Different natural factors have different effects on productivity improvement in different regions. Therefore, before the implementation of land consolidation projects, the work can be targeted in the light of local natural conditions. The method proposed in this study for evaluating the effectiveness of land consolidation combines remote sensing and spatial analysis techniques to systematically reveal the regularity of the impact of land consolidation on the productivity of arable land. Our method is significant for designing, implementing, and evaluating land consolidation projects, so it can be popularized and applied to research in related fields. However, the model establishes a relative yield relationship, which does not depend on the actual measured yield data, and the measured results are not the absolute capacity. Although it has a better application in this scenario, it ultimately does not reflect the actual yield change in arable land, so this direction should be improved in the future.

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Land Reforms Revisited: An Emerging Perspective on the Hellenic Land Administration Reform as a Wicked Policy Problem

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Abstract: This paper explores the complex nature of land reforms, arguing that they should be considered wicked policy problems by focusing on the Hellenic Land Administration Reform (HLAR). The article reflects on recent contributions that argue that the HLAR's challenges are associated with the great leap forward shift from a French-influenced deed paper-based system to a German-influenced digital cadastral parcel-based system. Another recent study contended that the legislative overregulation during the sovereign crisis period in the organizations of the diverse land registry systems of the land administration policy domain further complexified the reform process. A lack of consensus on the reform's main policy thrust and the means to achieve it was present both at the onset of the reform and during the economic crisis period, among the actors in the reform process. This paper contributes to the contemporary scholarly literature on land administration, integrating recent empirical contributions that point toward the wicked nature of land administration reforms.

Keywords: land reforms; wicked policy problems; Greece; Hellenic Cadastre System; conflict; complexity

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1. Introduction

Complex or intractable policy problems, often called "wicked" problems, have been a feature of public policy research since the early 1970s. Rittel and Webber [1] argued that systems analysis is no longer sufficient to tackle issues with a spatial dimension rationally, straightforwardly, and systematically. They espoused that scientists and engineers have traditionally focused on "tame" or "benign" problems. Tame problems may be solved using well-defined disciplines and specialties; only one actor is responsible for formulating policies to address them. A problem can be categorized as "tame" if it is clearly defined, or structured and standardized (quantitative) approaches and procedures are sufficient to tackle it. Technical approaches will not work, though, if a problem is poorly defined, "wicked" [1], "messy" [2], "ill-structured", or "unstructured" [3,4]. Some problems have fuzzy boundaries, making distinguishing them from other issues difficult. Addressing the whole problem is more than addressing each of its parts. One cannot be sure what disciplines and specialties should be used to solve wicked problems while dealing with them. Conflicting facts and values are intertwined, and numerous actors participate in policymaking [5].

Similarly, land-related issues are politically contentious when on a large scale, as in the case of land reforms, making them difficult to deal with and implement [6]. Land reform can broadly be classified into land redistribution (land transfer from large to small farmers) and land tenure or land administration reform (establishing secure and formalized property rights in land) [7–10]. Land administration theory's primary focus on developing, implementing, and monitoring cadastral systems to fulfill specified goals relies on scientific approaches in applied systems and the engineering paradigm, without emphasizing land reforms' complex (wicked) nature [11]. Nevertheless, land administration is about "humankind-to-land relationships" [12], which need to scale up efforts and integrate with other domains beyond legal and technical aspects [13]. Palmer et al. [6] argue that land reforms are inherently wicked, due to complex people-to-land relationships and their interrelation with the broader political, socioeconomic, cultural, and historical context. However, a systematic study of land reforms' wicked nature in the land administration literature is missing.

This paper argues that land administration reforms should be understood as wicked policy problems. We illustrate this claim by exploring the case of the Hellenic Land Administration Reform (hereafter HLAR or "the reform"). The HLAR is an entire overhaul of the country's land registry systems, with multiple components. It include the development of the Hellenic Cadastre System (HCS), a digital parcel-based cadastral system to replace the deed paper-based land registry system, namely the Registrations and Mortgages System (RMS), and a paper parcel-based land registry system, the Dodecanese Cadastre (DC). It also includes, among other things, the introduction of legislative frameworks and their harmonization with existing ones until their complete replacement, the modernization of technical infrastructure, and the institutional reform of land administration organizations. Long-simmering problems in land governance, including informal land tenure patterns, inefficiency, and fragmentation in the various existing systems from different legal traditions, are intended to be addressed by this comprehensive reform. The HLAR seeks to establish a uniform and transparent digital system with modern digital services that could facilitate sustainable development and economic growth by radically altering Greece's land administration policy domain. It was initiated in the mid-1990s as a large-scale public infrastructure project, following the idea of the unified and evidentiary multi-purpose cadastre and the tradition of the Germanic family of land books [14–21].

The outset of Greece's Land Administration Reform in the mid-1990s, co-financed by the European Commission, concurred with other land administration initiatives in central eastern European countries under the thriving Europeanization influence and the flow of European structural funds [22]. The development of the new cadastral system in Greece, the HCS, which lies at the core of the HLAR, has been characterized as "so complex that no one dares to say let us make it simple" [23]. However, the reform's implementation suffered from complications common in ambitious public sector projects, e.g., a multiplicity of stakeholders with conflicting expectations, over-optimism, political interference, media scrutiny, rigid bureaucratic procedures or guidelines, and cumbersome policies [24]. Thus, little progress had been made till the onset of the sovereign debt crisis in 2009, which found the cadastral reform at a critical juncture following the successful completion of the third Community Support Framework co-financing cadastral mapping projects [25]. Greece's bailout programs of 2010, 2012, and 2015, along with the accompanying Memoranda of Understanding (MoUs) with its international lenders, prioritized the completion of the HCS by 2020.

In this paper, we follow an argumentative and conceptual approach. We reflect on the existing literature to show how the HLAR embodies the main traits of wicked problems, complexity, and conflict [26], which are regarded as pertinent due to the reform's ambitious scope, the actors' high level of divergence, and prolonged implementation. The sources were chosen based on their empirical insights into HLAR and their applicability to various parts of the literature on wicked problems. Even though an analysis of the HLAR during the years of Greece's economic crisis is the main emphasis of this article, the tables in the paper include significant milestones up to the present day. This demonstrates a more comprehensive view that emphasizes the open-ended nature of the policy change, by highlighting how the crisis years paved the way for later developments, aligning with the relevant literature that demonstrates how crises serve as opportunities for reform [27–31].

Furthermore, this paper aims to advance the theoretical discussion on land administration reforms, stimulate further academic debates and research on policy responses, and provide insightful guidance for large-scale reforms in comparable contexts. To do so, we examine the associations between the characteristics of wicked problems [1] and the traits of land reforms [6] to illustrate the complexity and conflict inherent in land reforms, offering a novel approach in the contemporary land administration literature to enhance understanding of the wicked challenges and dilemmas [32] in land administration.

The paper is structured as follows: Section 2 reviews the literature on wicked policy problems, discusses what a wicked problem is and what the main characteristics of this type of problem are, and how they have been discussed in the literature on land reforms. In Section 3, we argue, based on recent research contributions [22,33,34], why the HLAR should be understood as a wicked policy problem by discussing the characteristics of the HLAR process and wicked problems. Finally, in Section 4, we summarize the paper's conclusion by reflecting on and contributing to the current understanding of the wicked nature of land administration reforms.

2. Literature Review

2.1. Wicked Problems: Origin, Definition, and Characteristics

"Hmm, those sound like "wicked problems"", responded West Churchman, University of California, after Horst Rittel's presentation on the differences between social and technical problems at the University of California, Berkeley, in 1967. The presentation was given in the context of a weekly seminar on these topics that West Churchman, a pioneer in groundbreaking operations research and system analysis work, organized following a NASA grant to investigate how technology from the space program could be applied to the world of urban problems [35]. Thus, Churchman's response and his first definition in a 1967 guest editorial in Management Science, credited to Horst Rittel, led to the genesis of the new field of wicked problems. These refer to «a class of social system problems which are ill formulated, where the information is confusing, where there are many clients and decision makers with conflicting values, and where the ramifications in the whole system are thoroughly confusing» [36] (p. B-141). Since then, when it first appeared in planning studies in the early 1970s, the concept of wicked problems has permeated many research disciplines.

The adjective "wicked" was initially intended to signify «the mischievous and even evil quality of these problems, where proposed "solutions" often turn out to be worse than the symptoms» [36] (p. B-141). The literature on wicked problems entails three broad categories of research agendas [37]. First, the concept itself [38–41]. Second, identifying a problem as wicked [42–45]. Third, how can a wicked problem be approached once it has been identified as such. This third category's literature stream emphasizes that in wicked policy problems, only imperfect, partial solutions or small wins are achievable in practice, and the significance of coordination and collaboration as a strategy for tackling wicked challenges and [26,46–54].

After the initial definition of wicked problems by Churchman, Rittel and Webber (1973) elaborated upon it and established the notion of wicked problems for which there are «no solutions in the sense of definitive and objective answers» [1] (p. 155). They distinguished between two types or classes of problems: "wicked problems" and "tame problems". They did not choose the word "wicked" to imply that problems are morally repugnant or in any other way indicative of the morals or values of the society in which they arise. Instead, they define a problem as wicked when it is elusive or difficult to determine. It is influenced by several complex social and political elements, some of which are related to the process of addressing the problem to be solved. They make the point that depending on the viewpoints and beliefs of the individuals interested in the problem, the nature of the wicked problem is likely to be interpreted differently. In contrast, while undoubtedly complex and technically challenging problems in, e.g., mathematics and engineering, are "tame" to the extent that the problems themselves can be clearly defined (and solved) by experts who produce clear, practical solutions using analytical approaches from their disciplines. Rittel and Webber [1] identified the following ten characteristics of wicked problems:

(1) There is no definite formulation of a wicked problem;
(2) Wicked problems have no stopping rule;
(3) Solutions to wicked problems are not true or false but good or bad;
(4) There is no immediate or ultimate test of a solution to a wicked problem;
(5) Every solution is essentially a "one-shot operation"; because there is no opportunity to learn by trial and error, every attempt counts significantly;
(6) Wicked problems have no clear solution and perhaps not even a set of possible solutions;
(7) Every wicked problem is essentially unique;
(8) Every wicked problem can be considered to be a symptom of another problem;
(9) There are multiple explanations for a wicked problem;
(10) The planner (policymaker) has no right to be wrong.

Following the initial identification by [1], several authors have attempted to define the fundamental dimensions or properties of wicked problems [41,49,51,54,55]. Most scholars agree that they are fundamentally distinct from other, tame problems. Early scholarship on wicked problems highlighted the dimensions of complexity and conflict, which differentiate wicked from tame problems. Pava [56] connected ill-defined, complex problems with non-synoptic systems change. These are sociotechnical and non-synoptic, i.e., fragmented and piecemeal, systems characterized by high complexity and high conflict. The conflict between actors can range from low to high and arise from contrasting values. Diversity of viewpoints between different interests results from several factors, such as the number of actors involved and the level of their divergence. The conflict may concern the ultimate ends of change, the means of accomplishing it, or the initial definition of the problem itself. The complexity of the phenomenon requiring change ranges from low to high. Complexity increases in messy situations with many intertwined or unstable factors.

Pava [56] argues that a systematic change in behavior and values is required to effect change in non-synoptic sociotechnical systems characterized by high conflict and complexity. Papoulias and Tsoukas [57] developed a typology of problems related to social reforms, where conflict and complexity range from low, such as the case of rational planning (i.e., budgeting and forecasting), in which traditional operational research methods are appropriate, to high, such as ill-defined experimentation referring to a large-system change. In this case, high-conflict of social reforms reflects how diverse the values, viewpoints, and interests are among those affected by the reform, and refer to the reform's goals, the means of implementation, or even the description of the problem the reform intends to solve. The complexity of the issues involved in a reform depends on how tame a particular problem is. The more discrete, solid, and isolatable the problems the reform intends to remedy are, the more analyzable they will be.

Hisschemoller and Hoppe [5] present a typology of four different types of policy problems classified into two dimensions. One dimension relates to the degree of (lack of) certainty regarding the knowledge of an unsatisfactory situation and the methods for making it more desirable. The (lack of) agreement on values is the other dimension. When there is a high level of consensus and certainty, a problem is said to be structured or tame. Dissensus on values and uncertainty about knowledge makes the problem "wicked", "messy", "ill-structured", or "unstructured". Between tame and wicked problems are the moderately structured problems [5]. A few years later, Roberts [41] condensed Rittel and Webber's (1973) wicked problem-related characteristics described above (1, 7, 8, and 9) and solution-related characteristics (2, 3, 4, 5, and 6) into just two dimensions: a lack of consensus on problem definitions, combined with a lack of consensus on solutions. Thus, three problems were identified: simple, complex, and wicked problems [41]. The high level of conflict among actors distinguishes wicked problems from simple and complex ones. There is no agreement on the problem or its solution in wicked problems. Head and Alford [49] succinctly contended that wicked problems are often related to societal heterogeneity (various interests and values of involved actors), institutional complexity (multi-level governance and inter-organizational overlapping), and scientific uncertainty (fragmentation and gaps in solid knowledge).

This section reviewed the origin, definition, main dimensions, and characteristics of wicked problems. In summary, it has been shown that there are two main dimensions of wicked problems: complexity and conflict. Since Rittel and Webber's study, various fields of public policy, political science, and public management have made additional advancements in understanding complexity and conflict as characteristics of wicked problems. The ten features of wicked problems, as initially identified by Rittel and Webber [1], continue to rule the discussion despite many new insights. In the next section, we present how wickedness has been discussed in the literature of land administration by Palmer et al. [6] and enrich the discussion on how their work relates to Rittel and Webber's properties.

2.2. The Wickedness of Land Reforms

Improving the effectiveness of a country's land governance, which may directly target reforming its land administration system, is a complex, politically sensitive, and highly resistant-to-resolution endeavor [6]. Reforms may include transforming a country's land administration system, which has been operational in its current form for a long time, or changing the organizations in charge of administering land, which entails changes to an organizational culture that has developed around the existing rules and procedures. Palmer et al. [6] argue that land reforms display the following traits: difficulty in defining the problem, a constantly evolving problem, lack of a clear solution, social and institutional complexity, and behavioral change being critical. Following this, we examine these traits, including examples of how aspects of these traits [6] are illustrated in case-specific land-related reforms, and we interrelate them with the characteristics of wicked policy problems [1]. The relationships identified below should be seen as a possible way of conceptualizing the interaction between the two sets of traits, rather than as a final or comprehensive classification, to provide a new perspective on how the features of land reforms correspond with the characteristics of wicked problems. Appendix A provides a complete reference for the visual depiction of these interrelations.

2.2.1. Difficulty in Defining the Problem

In land reform, there is difficulty in defining the problem clearly, since various actors have varying perceptions of the problem's nature, size, and scope. Each actor holds a puzzle piece, but none can see the entire picture alone. The available knowledge is fragmented among multiple actors, each holding some, but not all of that required to address the problem. Some information required to understand the problem may receive too much or too little attention because of how it is framed. The various actors may have interests (or values) that substantially conflict with those of other actors. Thus, different actors emphasize different parts of the problem and propose different solutions. Because of their differences in highlighting various aspects of the problem, there might not even be a complete, cohesive picture. Some proposals for solutions may have unanticipated effects, including detrimental effects on other system components; however, new opportunities may also emerge in this process. For instance, Almeida presented the complexity of a clear definition of the land-related issues in Timor-Leste, a country affected by post-colonialism, post-authoritarianism, and post-conflict challenges that the elected Timorese government faced after its independence: "The questions and their complexity were overwhelming" and "bringing justice to land-related grievances posed a very complex set of problems and dilemmas to the newly independent Timor-Leste" [58] (p. 135). In the case of formalizing property rights in informal settlements during South Africa's transition in the 1990s, the conflicting beliefs about land management, land administration, and the cadastral system were also apparent [59,60]. The slow pace of registration in the case of Romania's National Program of Systematic Land Registration was also attributed to a lack of a clearly defined problem and purpose [61].

The trait of difficulty defining the problem directly matches the characteristic that there is no definitive formulation of a wicked problem (1) [1]. It also relates to the lack of a clear solution (6) as a result of the weakness in defining the problem. The uniqueness of land-related issues pertinent to specific contexts relates this trait to every wicked problem being unique (7). Furthermore, given the path-dependent nature of land-related issues, the attempt to define the problem often reveals that these might be a symptom of another problem (8). In addition, the multi-stakeholder nature of land reforms contributes to the multiple explanations (9).

2.2.2. The Problem Is Constantly Evolving

Even if actors can agree on defining a land-related problem, the problem is constantly changing and evolving. The actors' comprehension of the problem may vary, since new aspects might emerge during implementation or new information might be generated. A political change could also open up and reveal fresh points of view; alliances and power dynamics may also vary over time. Vested interests adapt to reforms as well, coming up with new plans, ideas, or methods to protect the status quo or their interests. However, even if the problem is evolving, actors, political forces, resource availability, or a combination may determine the end of the design or land reform implementation for several reasons, including lack of resources and reform fatigue, among others [6]. A characteristic case of a constantly evolving problem is the policy reforms in East Africa and the West African Sahel to secure property rights in Africa's drylands. A new set of problems is created by policy initiatives to decentralize land allocation and administration to local governance levels and explicitly recognize and strengthen customary or group rights, such as, among others, the onset of a new round of resource user conflicts and the lack of accountability of local authorities [62]. The enduring reform process is also reflected in the case of Quebec's cadastral modernization program. In 1985, the project was initially evaluated at US$55 million. However, six years later, "85% of the initial budget had been spent, but the cadastre had been renewed for only 5% of Québec's 3.5 million properties" [63] (p. 3). The reform was suspended in 1991 and re-initiated in 1992 with "a 2006 completion target and an estimated budget of $508 million" [64] (p. 182). Nevertheless, these estimates were updated again in 2005–2006, and a new deadline for the cadastre's completion was set for the year 2021, with a readjusted estimated cost of $980 million [64].

Land reforms are characterized by their dynamic nature, given that new facets of the problem may come up during implementation, making a definitive formulation of land-related issues difficult. This aligns closely with several of Rittel and Webber's traits of wicked problems. First, there is no definite formulation of a problem, reflecting the constant redefinition of land reform challenges as new perspectives on the problem emerge (1). Second, the lack of a stopping rule (2) accentuates the iterative nature of land reforms, since advancements in one field frequently result in unforeseen challenges that call for additional interventions. Third, the characteristic that every wicked problem is essentially unique (7) relates to how land reforms have developed over the years in their specific sociopolitical and historical conditions, pointing out that there is no one-size-fits-all approach and that solutions cannot be replicated in other contexts. Fourth, the interdependencies of land-related issues often unveil deeper systemic problems (8). Addressing one aspect of the reform, such as land tenure, often reveals or aggravates other issues. Lastly, the evolving nature of land-related problems is due to the fact that each actor may frame the problem differently, or that actors' perspectives may shift over time, which aligns with the multiple explanations for a wicked policy problem (9).

2.2.3. Lack of a Clear Solution

Finding a clear solution is difficult when no clearly defined problem exists and the problem continually changes and evolves. Thus, actors may be forced to settle on "better", "worse", or "good enough" solutions in the absence of verifiably "right" or "wrong" solutions. Negotiations may lead to concessions that are not ideal, but the best that can be achieved at a given time. This could lead to the need for measures to "manage the problem" instead of "solving the problem". Without clear solutions, actors may struggle to persevere during the protracted reform process. Even when the problem continues, efforts to address it may end due to reform fatigue, changes or shifts in the political agenda or leadership, and a lack of resources [6]. A lack of a clear solution stemming from the "serious divergence" of the expectations among involved actors, such as the "producers (land surveyors), the users (government, ministries, landowners), the owners of the cadastre (the cadastral authorities) and the general public" was also encountered in Quebec's initial phase of the cadastre reform [63] (p. 4).

What is considered a "good" or "bad" option in land reforms frequently depends on competing agendas and interests. Reforms aimed at formalizing land tenure, for example, may favor investors at the expense of local communities, resulting in controversial effects. This directly reflects Rittel and Webber's characteristic (3), which affirms that solutions are judged as "good" or "bad" rather than "true" or "false". Furthermore, the impacts of cadastral systems are frequently challenging to quantify, as their long-term outcomes unfold over decades and remain subject to debate. Therefore, this trait relates to the fact that there is no immediate or ultimate test for a solution (4). The high stakes of land interventions that affect property rights, where every attempt has significant repercussions, tie this trait to the characteristic (5). In addition, there is a direct match with Rittel and Webber's characteristic that wicked problems may lack a defined set of possible solutions (6). Last, policymakers have to be aware of and sensitive to decisions that might hike resistance, raise litigations, or induce other unforeseen consequences (10).

2.2.4. Social and Institutional Complexity

High levels of institutional complexity characterize land reform. A constellation of many co-competent organizations in the land sector often undermines reform efforts [6]. Competing sources of legitimacy and power are evident in the fragmented nature of the land sector. It often comprises a broad spectrum of governmental organizations, professionals, and civil society actors. State responsibilities are often split between numerous ministries and departments, posing unique reform hurdles. The coordination of many actors with multiple and frequently divergent interests over time is difficult and complex at best, and frequently impossible to sustain. The challenges at hand are far too complex and multifaceted for any single institution, no matter how large. Addressing a mess requires a multi- and inter-organizational reaction capability [65]. Paunescu and Paunescu [66] provide an account of the institutional complexity and weaknesses of Romania's land administration reform, resulting in poor and inconsistent coordination among local authorities, cadastral organizations, surveyors, and citizens and the slowing down of its progress. The institutional complexity of Romania's case and its path dependency is illustrated by Hernandez [67], who presented how Romania's land registration system in the early 2000s was managed by the different institutions of the Ministry of Justice (Land Books offices) and the regional offices of the National Cadastre Organization. Moreover, the Ministry of Agriculture was administering rural land reform, issuing property certificates to "newly defined private owners" [67] (p. 6).

Social complexity is inherent to land administration reforms, which challenge existing land tenure regimes through land titling formalization programs to build cadastral systems. The land tenure system consists of the rules governing how land is owned, used, managed, and transacted in a society [68]. It includes formal rules (e.g., laws and regulations) and informal rules (e.g., social norms and customs), which may not always align perfectly with each other. This dissonance creates a gap where social legitimacy (how people perceive and accept land rights) may not always match legal legitimacy (what is formally recognized by law).

Hull et al. [10], who studied various land reform theories and their impact on the success of reform initiatives in the cases of Southern Africa, Nigeria, and Mozambique, highlight that imposing formal land titling systems onto customary land tenure arrangements can lead to conflicts and unintended consequences; therefore, they call upon designing appropriate and context-sensitive land administration systems [10]. Similarly, Almeida [58] explored the limitations of legal approaches in addressing land grievances in Timor-Leste, how the introduction of formal land laws often overlooks the complexities of existing land tenure systems inherited during the Portuguese colonial era and Indonesian occupation, and the "disconnection between the law in the books, the work of the public administration and the practices on the ground" leading to 'wicked problems'—issues that are difficult to define and inherently unsolvable through "the linear thinking of the law" [58] (p. 146). The complex nexus between informality and the law in unauthorized settlements, a phenomenon not only visible in the Global South but also in other contexts in Southern Europe such as Italy [69], Greece, and Albania [70–72], and its implications in land-use regulation and planning (however, relevant to land administration reform efforts as well), has been studied by the authors of [73]. They propose considering the concept of nomotropism, which means "acting in light of rules" and not necessarily "in conformity with rules" in introducing regulations and institutional design, in "a sort of "goodness of fit" between the introduced rules and the larger context in which they are set" [73] (p. 166) so as to reduce the gap between their social and legal legitimacy.

Social and institutional complexity is related to difficulties in having a consensus on problem definitions and solutions for land reforms due to the involvement of multiple actors with competing interests. Thus, this trait is related to Rittel and Webber's wicked problem characteristic [1] that solutions to wicked problems are not true or false but good or bad (3), relying on the viewpoints of several actors and multiple explanations of the problem (9). Furthermore, every decision, action, or attempt in land reform "leaves "traces" that cannot be undone" [1] (p. 163) or might have unforeseen repercussions, damaging trust or intensifying disputes among the numerous actors. Therefore, land reforms should evolve cautiously, relating this trait with Rittel and Webber's characteristic that "every solution to a wicked problem is a "one-shot operation"; because there is no opportunity to learn by trial and error, every attempt counts significantly (5). The social and institutional complexity is also related to every wicked problem is essentially unique (7). Cultural norms, land tenure patterns and practices, legal frameworks, power dynamics, and political and historical aspects characterize the intrinsically distinct context in which land administration takes place. Therefore, solutions must be customized appropriately and cannot be readily transferred from one context to another.

2.2.5. Behavioral Change Is Critical

Palmer et al. [6] emphasize that behavioral change is critical in land sector reforms. They usually necessitate alterations to corporate culture, citizens' behavior, and land professionals' conduct. Land professionals may have established ideas regarding technical, legal, and procedural standards that make reform difficult. Moreover, the implementation of land administration reforms can be challenging for employees working in an environment with complex procedures. Their capacity to adapt to developments taking place on the ground may be restricted by donor requirements that are predicated on quick results [6]. This trait demonstrates the difficulty of modifying behaviors and embracing change. Such alteration in land surveyors' professional practices and activities, as well as the necessity to adapt to the new realities and complexities that emerged from the creation of a unified global cadastral map to replace single parcel-based paper maps, are evident in Quebec's cadastral reform, a program of "unprecedented scope, and unique in terms of methodology and final product characteristics" [64] (p. 181).

Solutions to land-related issues are evaluated based on their perceived effectiveness and fairness, with poor implementation requiring adaptation by involved actors to mitigate unintended consequences or modify the solution. Therefore, the trait of behavioral change [6] is related to Rittel and Webber's idea that solutions are not true or false, but good or bad (3). It is also related to every wicked problem being essentially unique (7). Land reforms take place in particular settings. Therefore, strategies to engage stakeholders to implement them should be adjusted to specific contexts, due to their unique institutional or cultural elements. In land sector reforms, actors' behavioral patterns are frequently linked to more general systemic problems like resource injustices, red tape, or ingrained power dynamics. Opposition to land reforms is often a sign of more serious, deep-rooted, and interrelated issues. To overcome these obstacles, it is frequently necessary to address the underlying systemic problems concurrently. Therefore, the importance of behavioral change is related to Rittel and Webber's characteristic that every wicked problem can be considered a symptom of another problem (8). It is also related to the characteristic that the planner (or policymaker) has no right to be wrong (10). Designing or implementing land reforms often entails risk and uncertainty. Therefore, policymakers must also adjust their behavior by being cautious in designing and making changes that might affect property rights and the people-to-land relationship, and thus result in opposition.

In this section, we presented some of the main challenges that are common in land administration reform efforts globally, linking the traits of land reforms as identified by the authors of [6] with the characteristics of wicked policy problems as identified by the authors of [1]. In the next section, we discuss the HLAR regarding the main traits of wicked policy problems, such as conflict and complexity, since they represent their key components, as described in the pertinent academic literature on wicked problems. Complexity reflects wicked problems' multifaceted nature, which includes interdependencies among different systems and actors involved, as well as institutional, legal, and technical hurdles. Another key characteristic of wicked problems is conflict. Conflict frequently stems from long-standing disagreements in the beliefs, objectives, and interests of the people impacted by a policy change and the definition of the problem or its resolution.

Although these issues are prevalent in land reform initiatives around the world, stemming from their multi-actor nature, institutional interdependencies, and long-term societal implications, the HLAR exemplifies how institutional, cultural, and political elements interact uniquely in Greece, and how these traits proliferated during the period of the economic crisis. The discussion section will provide a detailed analysis of these factors.

3. Discussion

The Hellenic Land Administration Reform has been a long and iterative process, reflecting the complexity and conflict inherent in the reform. To demonstrate the intricacy and iterative character of the HLAR, two separate tables are provided in Appendix B, compiled from secondary sources, highlighting both key legislative and policy milestones (Table A1) and the implementation progress of the HLAR (Table A2). This timeline of significant events illustrates how regulatory changes, institutional reorganization, and external impacts have all contributed to the reform's ever-shifting challenges and progress. While at the onset of the sovereign debt crisis in 2009, 17% of total property rights had been registered in the new HCS (6% of the total Greek territory), at the end of the crisis in early 2018, the figure increased to 28.7% of total property rights (7.8% of the area) (Table A2). The HLAR is currently in full expansion, following decisions and choices taken and milestones set during Greece's economic crisis.

3.1. Complexity

There are several approaches to explain why there is a distance between a problematic situation and what "ought to be". The type of problem-solving approach depends on the explanation selected [1]. In Greece, the lack of cadastre was explained as the cause of the encroachment on public lands, extensive informal development, deforestation, land speculation and cumbersome procedures in land transactions, expropriation, and property law. Thus, the solution prioritized in the mid-1990s was obtaining a cadastre and fulfilling a long-standing quest to "catch up" with the most advanced Western European democracies [33,74]. According to the predominant connotation, as applied in continental Europe, cadastres serve the state to facilitate the collection of land taxes, whereas legal land registries serve the needs of the citizens, to publicize conveyancing and land transactions [75–77].

The HLAR is characterized by structural complexity, visible in the intractability of the large-scale systems change that the reform entails: the transition from the Registrations and Mortgages System and the Dodecanese Cadastre and of diverse land tenure regimes to the Hellenic Cadastre System. Early discussions in the Greek domestic academic and professional legal discourse demonstrated a preference for the German system of land books [78,79], moving from the Napoleonic tradition of the person and paper-based Registration and Mortgages System, which had operated in the country since the mid-19th century. However, the actors who define the problem have the advantage of the first move, which eliminates the attempts from other actors to redefine it [80]. Thus, it was the professional and academic community of the surveyors who put forward the development of the cadastre, which followed the most advanced cadastral exemplar in the mid-1990s: a parcel-based cadastral system, which would consist of a land registry and a cadastre component and would be digital and serve multiple needs, either for the benefit of the state or of the private vendees for securing and publicizing land transactions [20,33]. The initiation of the HLAR brought a paradigmatic change in the policy goals that a land registry system would serve: to reveal and protect public property; secure revenue from land taxation and land transactions; underpin spatial planning; support land policy; end state property encroachment and property disputes; and prevent informal development and deforestation [22].

Initiating a new land registry system from scratch (ab initio) in the mid-1990s signaled the prioritization of a solution with great inherent complexity. The onset of the reform had to put forward new organizations, IT infrastructure, procedures, and norms, and ultimately, the first cadastral registration process, the so-called adjudication process, implemented through outsourcing cadastral surveying projects to register property rights and classify private and public property. The latter necessitated delineating forests, forest lands, and seashores, which, according to national legislation, are considered predominantly public land. It also had to define how and which organizational entities would operate the new system, either at a final stage or in the intermediate period, and how they would gradually expand throughout the territory [33].

Head and Alford [49] demonstrated that institutional complexity, namely multi-level governance and overlapping responsibilities, characterizes wicked problems. Similarly, Palmer et al. [6] argue that institutional complexity is one aspect of reforms in the land sector. These reforms rarely fall neatly within the purview of any single organization, and this characteristic applies in the case of the HLAR. The HLAR evidenced complexity in the diversity and number of organizations involved. At the onset of the reform in the mid-1990s, the Hellenic Cadastre and Mapping Organization (HEMCO), a public legal entity established in 1986, was mandated to be responsible for operating the HCS at the final stage through its regional cadastral offices.

Furthermore, a more flexible private legal entity founded in 1995, namely KTIMATOLOGIO SA, would contract out the cadastral registration, i.e., the adjudication process. The output of the adjudication process, namely the first cadastral registrations, was assigned to be operated by the plethora of public, private, and notary-run mortgage offices supervised by the Ministry of Justice. The development of the HCS required collaboration with other competent authorities, such as the Forestry authorities, the Public Property authorities of the Ministry of Finance, the Ministry of the Environment, the local authorities, and the Ministry of Agriculture, among others [34].

As the HLAR proceeded and unfolded throughout the territory, new complications started to emerge, stemming from financial constraints, the technology required to be set up, the legacies of complex regimes of de facto land tenure, or the extended informality in Greece [70–72], along with the specific administrative capacity of the variety of institutions involved in implementing reforms [34]. Thus, the reform's scope or ambition level was impacted significantly over time, adjusting to the emerging complications and constraints.

From 2009 to 2018, during Greece's public debt crisis, the implementation of the HLAR within the overarching structural reforms that the Economic Adjustment Programs (EAPs) introduced was further complexified. The HLAR was associated with policy conditionality, encompassing a series of obligations with stringent deadlines [22,25]. As with other reforms that were included in the structural reforms of the EAPs, the HLAR had to fulfill specific requirements within specific deadlines to enable the release of the installments of the bailout loans in a fragile economy [81]. Furthermore, collecting revenues from several sources, such as the privatization of public property, fees from property transactions, and real estate taxes was critical for the Greek government to satisfy urgent fiscal needs. Beyond the drastic fall of land transactions in the real estate market due to the economic recession, the old land registry system, namely the RMS, was suffering from the lack of an efficient, modern, and transparent mechanism for collecting land transactions fees directly to the public budget [22].

Institutional and procedural complexity were significantly exacerbated by overregulation in Greece's land administration policy domain, particularly during the economic crisis period (2009–2018). Balla et al. [22] argued that the reform process was characterized by the proliferation of laws, regulations, and organizational restructuring initiatives under intense external pressure and policy conditionality, with some of these responding to different goals. For instance, several legislative initiatives were undertaken during the period 2009–2018 to address the impact of the economic crisis on the operation of the RMS and the collection of land transaction fees [22]. Furthermore, the prioritized acceleration of the new HCS was aimed for, to secure fiscal revenue through the real estate tax as well as attract new investment, including foreign direct investment, by providing legal certainty regarding property rights in the real estate market. However, instead of incremental first-order changes to improve ineffective practices and services for citizens, the legislative overregulation in the policy domain was characterized by drastic second-order changes. For instance, too many significant changes to the land administration policy domain were included in the 4512/2018 Law to be implemented simultaneously. The 2018 statute is a noteworthy example of organizational change that affected the long-standing institutional field dispositions in which the land administration organizations were situated, by abolishing the National Cadastre and Mapping Organization (NCMA) and the almost 400 mortgage offices, either public, private, or notary-run, scattered around the country. Following this organizational change several repercussions, such as extreme delays in land transactions or in the operation of the newly formed public organization were identified Earlier, in 2013, HEMCO was abolished, and some of its responsibilities were transferred to the KTIMATOLOGIO SA, which was renamed NCMA, reversing one of the initial policy choices at the onset of the reform in the mid-1990s [22]..

Furthermore, tinstitutional restructuring made things harder due to austerity measures for understaffed organizations, to provide efficient services, adding to their administrative costs. Employees suffered from reform fatigue since they had to balance competing agendas and follow an ever-growing list of procedural requirements. Overall, the legislative overregulation during the economic crisis is apparent in the six (6) legislative initiatives that have been undertaken affecting Greece's land administration organizations [22], without encountering other legislative initiatives inherent to the HLAR, such as for forest maps indicative of the complex nature of HLAR (Table A1, Appendix A).

3.2. Conflict

Conflict was a vital feature of the HLAR from its onset, between the two competing frames on the solution that was prioritized in the mid-1990s. On the one hand, it was the technical frame [82], as represented mainly by the policy community [83,84] of the Ministry of Environment and technical professionals, to push forward the solution of the HCS. On the other hand, it was the legal frame, as represented by the policy community of the Ministry of Justice and the legal professionals, such as the private registrars and occasionally the notaries, who were opposing the prioritized solution of a newcadastral system from scratch that would combine a legal and a spatial component and were proposing the preservation and modernization of the existing land registry system (RMS) and the creation of a mapping infrastructure, to be distinctly supervised by the Ministry of the Environment. The predominance of the technical frame, which put forward the reform over the alternative solution that was promoted by the legal frame, induced a conflict between the actors of the new and the old system [34]. The conflict between these two frames, the legal and the technical, remained relatively moderate while the development of the new system, the HCS, was delayed in bringing results. Besides, the foundational cadastral law of 1998 ensured (article 23 L.2664) that the old RMS's principal actors, such as the registrars and the employees in the mortgage offices, would be operating the new cadastral system, the HCS, in the transition period, without any change to their employee status. Furthermore, the law ensured that at the final stage, the employees of the mortgage offices would be transferred to the cadastral offices to operate the new system. For the registrars, the 1998 law ensured accordingly that they could be appointed to the position of Head of the Cadastral Office, or if they did not wish to become employees in the cadastral offices, they could be appointed as notaries or lawyers [34].

The economic crisis onset at the end of 2009 opened a policy window [85]: the completion of the HCS fitted ideally as a solution to the challenges associated with the crisis and the EAPs' priorities. The promise of the new system to reveal public property and solve property disputes regarding public assets [86], was in alignment with the goal of reducing public debt through privatizations and the exploitation of public property. Furthermore, the promised increase in public revenues through a more transparent land registry system, which would facilitate the collection of land taxes and transaction fees, was consistent with the overarching goal of the EAPs to reduce the public deficit. Moreover, the formalization of property rights was appealing to resolve property disputes in private property, to boost economic development and attract foreign investments.

During the sovereign economic crisis, new actors came in with their own normative beliefs, preferences, and frames [82,87]. This contributed to increased opportunities for conflict in the reform process. Policy conditionality was accompanied by technical assistance to support the Greek government in the reforms associated with the MoUs. International actors had either an enforcement role (troika) or not (technical assistance). In this period, a new frame, the economic frame, as represented by the policy community of Greece's international lenders and foreign technical assistance, which prioritizes the new cadastral system as a solution to the country's move towards a new economic model and securing revenues for the country's fragile fiscal conditions, became apparent. Thus, the normative beliefs of foreign actors coincided with some local actors' normative beliefs and pursuits. They all prioritized the completion of the cadastre [34]. The acceleration of the HLAR, included in the EAPs from 2010 onwards, was aligned with the prioritized solution of the economic and technical frames to push forward the reform [34].

On the other hand, the interests of the various actors in the policy community of the legal frame were diverse. Private registrars of big private registry offices were consistently against the new system, while the registrars of small private registry offices were less resistant to the transition to the new system, which they had operated for many years during the transition phase, namely, the period in which both the old RMS and the new HCS were operated [25,34,88,89]. The employees of the private registry offices were eager to become public servants, thus leaving behind job insecurity. The employees of the public registry offices were unwilling to join the new cadastre organization, but to remain judicial public servants and be transferred to the Ministry of Justice or other related authorities, keeping their status [90,91]. Nevertheless, even if there were different perceptions of the means to implement the reform, finally there was an alignment in the last and most critical phase, to proceed with the implementation of the reform in a big bang approach by contracting out the cadastral mapping in the rest of the country, and the organizational transformation [34].

The HLAR during the sovereign debt crisis occurred in the context of the country's structural adjustment, which was introduced with the bailout agreements and the associated economic adjustment programs, accompanied by policy conditionality [92,93]. The "normative isomorphic mimicry", in which organizations or countries adopt best practices, coincided with the "coercive" isomorphic mimicry, in which agents force isomorphism on an organization or country [94]. Undoubtedly, land tenure security, the promised outcome of the HLAR, ideally fitted the need for legal certainty on property rights. The latter has been included in the structural reforms driven by policies spawned by the Washington Consensus [95] and funded by international organizations like the International Monetary Fund (IMF) and the World Bank, to boost economic growth and enhance a country's competitiveness. Furthermore, foreign technical assistance in the cadastre domain encouraged the domestically nominated and prioritized perception that the lack of a cadastre constitutes a problem and advocated accelerating cadastral development and completion of the cadastral reform [34,96–101].

Nevertheless, policy conditionality and external empowerment [102] were decisive in bending any resistance towards the creation of one single organization to manage the country's land registry systems at the end of the period of the economic crisis, which would undertake the conversion and merging of the mortgage offices of the RMS and the cadastral offices of the DC into the creation of the final cadastral offices of the HCS, and the contracting out of the adjudication process in the rest of the country, when it was doubtful whether it would otherwise occur at that moment [22,34,103–106]. The sovereign debt crisis was a critical juncture [28,107] and functioned as an accelerator, based on the land administration's predominant discourse to push the reform process forward. Under extreme financial duress and policy conditionality, this kind of policy diffusion points to an interesting mixture of coercion and mimicry mechanisms [94,108–110].

In this section, we discussed the case of the HLAR through the lens of complexity and conflict, revealing the persistent and evolving challenges inherent in the reform process, which proliferated during the period of the country's economic crisis. The complexity of Greece's reform and its inherent conflict indicates the difficulty in implementing land administration reforms on a large, national scale, which involves multiple institutions and large numbers of people and resources [47], through radical shifts in existing land registry systems that aim to formalize diverse land tenure regimes fully. Nevertheless, as Palmer et al. [6] argue, land reforms have shown us that there is no quick fix. Building national consensus and support for land reforms takes time and money, and "if land reforms are rushed and under-resourced, they will be chaotic, incomplete, and ineffective" (p.33). Furthermore, these findings about Greece's land administration reform further align with the traits of third-order policy change [111], which similarly entails high levels of complexity and conflict, highlighting the intricate nature of such reforms. The following section concludes by highlighting the findings and suggesting directions for further study to deal with land administration reforms as wicked policy problems.

4. Conclusions

In this paper, we argued that land administration reforms should be understood as wicked policy problems. We used the HLAR as an appropriate case, and we analyzed aspects of the reform process through the lens of the main characteristics of a wicked problem. We found that the reform process, which entails, among others, transitioning from outdated land registration systems of different legal traditions to a unified, digital cadastral system, exhibits the characteristics of conflict and complexity, supporting our claim that the HLAR should be seen as a wicked policy problem, not a technical or a tame one. The ambitious design of the reform, combined with pre-existing issues like fragmented and overlapping land administration responsibilities, conflicting actors' interests, and land tenure patterns, set the stage for its complexity. The economic crisis, which served as an opportunity to hasten the reform's endeavor, acted as a trigger that revealed and exacerbated latent complexities embedded in the reform's design and amplified political instability and resource constraints, increased conflict, accelerated rushing to solutions under crisis conditions, and favored large-scale interventions and reversals of initial policy choices, thus intensifying the inherent challenges of the reform.

By analyzing the HLAR within the theoretical framework of wicked problems, this study draws attention to the inherent resistance of land reforms to resolution, using linear or technocratic approaches. The paper contributes further to the current literature on land administration by offering a structured way to examine land reform processes through the associations between the characteristics of wicked problems by Rittel and Webber [1] and the wickedness of land reforms, as discussed by Palmer et al. [6]. The insights from this study may assist other jurisdictions in their efforts to achieve Sustainable Development Goal 1.4.2 through state-led land administration reforms. Future empirical studies are needed to validate and expand upon the current findings, due to their dependence on the authors' past empirical studies and the argumentative and conceptual approach of this paper. Further research could also incorporate comparative analyses with other countries' reforms to shed light on different approaches and techniques for addressing challenges in land administration and assessing their effectiveness. Exploring adaptive, participatory, transdisciplinary, and collaborative approaches, as well as iterative processes of experimentation and learning, may provide valuable insights for tackling the dynamic and contentious nature of land administration reforms [112–115]. These approaches, which emphasize small-scale interventions, tracking results, and developing adaptation plans based on emerging challenges and opportunities, could enhance the resilience and responsiveness of reform efforts. They also encourage collaborative problem solving, adaptive management, and focusing on the process rather than predefined outputs. By employing these tactics, reformers may achieve more sustainable and efficient methods for addressing the wicked nature of land administration reforms, acknowledging that such problems cannot be "solved" but only managed over time.

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Data Availability Statement: The data will be published in DANS Easy repository, and access can be granted by taking the ethical considerations and privacy restrictions into account.

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Appendix A. Conceptual Mapping of Land Reforms' Traits and Wicked Problem Characteristics

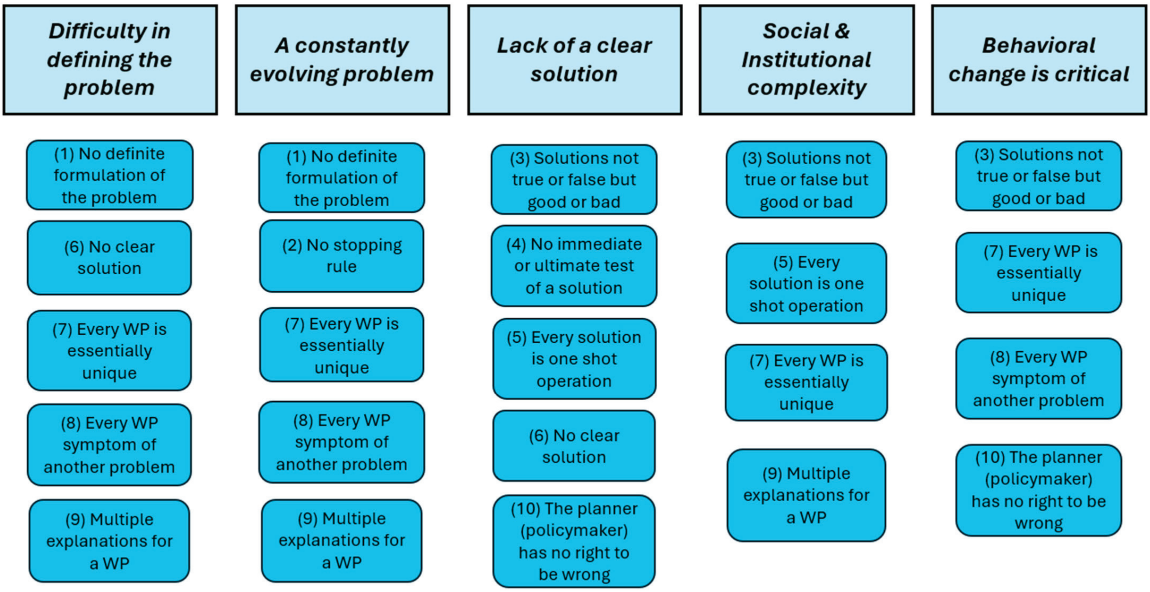

Figure A1. Relationships between Palmer et al.'s traits of land reforms and Rittel and Webber's wicked problem characteristics. Note 1. This diagram illustrates the alignment (vertically) between Palmer et al.'s traits (upper level) and Rittel and Webber's wicked problem characteristics, reflecting the authors' interpretation. The numbers in parentheses correspond to the numbering of Rittel and Webber's characteristics, as discussed in Section 2.1 in the text.

Appendix B. Tables

Table A1. Key legislative and policy milestones in the HLAR compiled by the authors based on multiple sources (See the list of sources below).

Year	Milestone	Significance
1995	Law 2308/1995	Foundational law providing the legal framework for the cadastral adjudication process.
1998	Law 2664/1998	Foundation law providing the legal framework for the operation of the Hellenic Cadastre System (HCS).
2001	Constitutional Amendment	Reinforced the mandate for establishing a comprehensive land and forestry registry system.
2010	1st EAP	Provided the acceleration of the reform and set the milestone for completion in 2020.
2010	Law 3889/2010	Provisions for the ratification of forest maps.

Table A1. *Cont.*

Year	Milestone	Significance
2012	2nd EAP	Provided, among others, the acceleration of the reform; strict deadlines for the validation of forest maps and delineation of coastal zones; tendered the cadastral projects in the rest of the country; streamlined property transfer procedures for tax purposes; and set the milestone for completion in 2020.
2013	Law 4164/2013	Abolition of HEMCO; simplification of procurement procedures.
2014	Law 4280/2014	Forestry Regulation Legislation (Chapter C).
2015	3rd EAP	Provided, among others, the adoption of a new legislative framework about forests and the preparation of forest maps; to set up a new organizational structure to operate the HCS; to proceed the cadastral registration in the rest of the country.
2016	Law 4389/2016	Accelerated forest map preparation, verification, and validation (Chapter Θ).
2018	Law 4512/2018	Established the framework for merging land administration organizations (of the HCS, RMS, and DC) (Chapter A).
	August 2018	End of Economic Adjustment Programs—Onset of Enhanced Surveillance (till 2022)—HLAR progress continued to be monitored by EU authorities.
2020	Law 4685/2020	Provisions for forest maps and unauthorized land-use changes in forests.
2021	Law 4821/2021	Acceleration of completion of the HCS; correction of first registrations; and licensed surveyors to update the cadastral maps.
	PD 3/2021	Transfer of responsibilities of the HELLENIC CADASTRE to the Ministry of Digital Governance
2022	Law 4915/2022	Regulates state ownership rights in land plots which have been afforested (Article 93).
	Law 4936/2022	Regulates state ownership rights in land plots that have been afforested in the cadastral registration process (Article 40).
	Law 4934/2022	Provision for the inclusion of the areas pertinent to DC in the HCS and harmonization of legal frameworks.
2023	Law 5076/2023	Acceleration of completion of the HCS; handling pending registering deeds to the HCS; strengthening operational capacity of the HELLENIC CADASTRE; and simplification and acceleration of property transfer.
2024	Law 5142/2024	Acceleration of cadastral registration to complete the HCS; simplification of procedures; introduced AI in land administration; provisions for the operation of the HELLENIC CADASTRE.
	Sources for Table A1	• Law 2308/1995, Government Gazette No. 114A/15.6.1995; • Law 2664/1998, Government Gazette No. 275A/03.12.1998; • Law 3889/2010, Government Gazette No. 182A/14.10.2020; • Law 4164/2013, Government Gazette No. 156A/09.07.2013; • Law 4280/2014, Government Gazette No. 159A/08.08.2014; • Law 4389/2016, Government Gazette No. 94A/27.05.2016; • Law 4512/2018, Government Gazette No. 5A/17.01.2018; • Law 4685/2020, Government Gazette No. 92A/07.05.2020; • PD 3/2021, Government Gazette No. 3A/06.01.2021; • Law 4821/2021, Government Gazette No. 134A/31.07.2021; • Law 4915/2022, Government Gazette No. 63A/24.03.2022; • Law 4934/2022, Government Gazette No. 100A/23.05.2022; • Law 4936/2022, Government Gazette No. 105A/27.05.2022; • Law 5076/2023, Government Gazette No. 207A/13.12.2023; • Law 5142/2024, Government Gazette No. 158A/04.10.2024; • Economic Adjustment Programs of Greece, European Commission.

Table A2. Progress of the HLAR (simplified) compiled by the authors based on multiple sources (See the list of sources below).

Year	Activity	Progress Achieved
1995–1999	Initiation of the first-generation cadastral pilot programs	Early groundwork for mapping and registration.
2008	Launch of second-generation cadastral projects	Accelerated cadastral registration in urban areas.
2009	Onset of crisis	Cadastral registration completed of 17% of total property rights—6% of the country's area.
2011	Procurement of third-generation cadastral projects	Targeted ~18% of the country's property rights (~26% of the area) in peri-urban and rural areas.
2016	Procurement of fourth-generation cadastral projects	Targeted ~42% of the country's property rights (~63.4% of the area) covering an additional 4000 municipalities, including in rural and mountainous areas.
2019	EC co-funding of fouth-generation cadastral projects	Boosted progress with EC approval co-financing, with funds from the European Regional Development Fund (ERDF); cadastral registration completed ~33% of property rights (8,8% of the country's area).
2021	Digitizing the mortgage offices' registry books	Initiation of the project (procurement) to digitize registry books to enhance access to old land registry records and facilitate property transfer procedures.
2023	Accelerated efforts toward completing 100% cadastral coverage; organizational restructuring	Cadastral registration completed ~42% of property rights (15% of the country's area); creation of 14 cadastral offices and 69 branches; forest maps validated for 88,5% of the total area.
2024		cadastral registration rate ~52% of total property rights at the end of 2024.
2025	Projected completion date of the adjudication process	Abolishment of ~390 mortgage offices and creation of 17 cadastral offices and 75 branches in January 2025; Aiming to achieve national cadastral registration by the end of 2025.
	Sources for Table A2	• Report of Activities of the Year 2019, Hellenic Cadastre; • Report of Activities of the Year 2023, Hellenic Cadastre; • Balla, Evangelia. "The Hellenic Cadastre". In Reforms in Public Administration during the Crisis (in Greek), edited by Calliope Spanou, 98–159, Hellenic Foundation for European and Foreign Policy (ELIAMEP); • European Commission, 2019, "Cohesion Policy invests in a modern and reliable property register in Greece", https://ec.europa.eu/regional_policy/en/newsroom/news/2019/01/24-01-2019-cohesion-policy-invests-in-a-modern-and-reliable-property-register-in-greece (accessed on 25 January 2025).

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