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Rural Land Management Interaction with Urbanization

Edited by
Carmen Delgado-Viñas and María L. Gómez-Moreno

Printed Edition of the Special Issue Published in *Land*

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This is a reprint of articles from the Special Issue published online in the open access journal *Land* (ISSN 2073-445X) (available at: https://www.mdpi.com/journal/land/special_issues/ru_urbanization).

For citation purposes, cite each article independently as indicated on the article page online and as indicated below:

LastName, A.A.; LastName, B.B.; LastName, C.C. Article Title. *Journal Name* **Year**, *Volume Number*, Page Range.

ISBN 978-3-0365-6552-1 (Hbk)
ISBN 978-3-0365-6553-8 (PDF)

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Article

Mining, Urban Growth, and Agrarian Changes in the Atacama Desert: The Case of the Calama Oasis in Northern Chile

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Abstract: Since the mid-twentieth century, Latin American rural territories have undergone significant transformations. One of the leading causes is the expansion of large-scale operations that exploit natural resources for world market exportation with low processing. In this paper, we study the changes in agricultural activities, livestock, and land use in the Calama oasis (the Atacama Desert, northern Chile) in relation to the growth of large-scale copper mining and other chained processes (urbanization and increased demand for water resources); based on a mixed methodology combining descriptive statistics, archival and bibliographic review, ethnography, and spatial analysis. We present the results through a historical reconstruction of the analyzed dimensions and their relationships, accounting for contradictory dynamics in time and space. We identify how mining and urban growth promote some agricultural and livestock activities under certain economic and political conditions, while in other contexts, these activities have been severely weakened, seeing increasing urbanization of rural land, rural-urban pluriactivity, and a growing deagrarianization.

Keywords: extractivism; capitalist periphery; rurality; urbanization; rural-urban pluriactivity; deagrarianization; depeasantization; rural proletarianization; south-central Andes

Citation: Calderón-Seguel, M.; Prieto, M.; Meseguer-Ruiz, O.; Viñales, F.; Hidalgo, P.; Esper, E. Mining, Urban Growth, and Agrarian Changes in the Atacama Desert: The Case of the Calama Oasis in Northern Chile. *Land* **2021**, *10*, 1262. https://doi.org/10.3390/land10111262

Academic Editors: Carmen Delgado Viñas and María L. Gómez-Moreno

Received: 27 October 2021
Accepted: 17 November 2021
Published: 19 November 2021

1. Introduction

Since the mid-20th century, global capitalism, national development policies, and widespread urban growth have driven a diverse array of significant environmental, economic, political, and cultural transformations in a significant part of the planet's rural zones [1–4]. In Latin America, agricultural systems and rural land use have undergone considerable modifications, caused by major transnational capital investment, the weakening of smallholder agriculture, rural pluriactivity, urban growth, the overextraction of natural resources, and greater urban–rural interaction, among other things [5–10].

To understand the changes that have occurred in Latin America's rural areas over an extended period of time, it is important to consider that, historically, the continent's participation in the global economy has been based upon the widespread exportation of largely unprocessed natural resources, or extractivism [11–17]. Theoretically, extractivism is a pattern of accumulation that develops in the peripheral areas of global capitalism. As a worldwide economic system, capitalism has historically been organized on the basis of relations between central and peripheral areas. The centers are the preponderant spaces of accumulation, dominating the world market and the production of complex goods with advanced technology. The peripheries export mainly raw materials and foodstuffs to the centers, transferring surplus labor and natural resources [18–22]. Extractivism, as a pattern of accumulation, is expressed in different types of extractive activities. Extractive operations of all kinds, whether forestry or agricultural monocropping, industrial livestock production and fishing, aquaculture, hydrocarbon extraction, mining, and natural resource-based energy production, are situated in—and directly affect—rural zones. Consequently, these activities have become a determining factor in how rural zones are socially and spatially configured, as well as how they have varied over time and space. In fact, in its development, extractivism has generated different struggles in rural areas between large companies, states, indigenous peoples, and rural communities, among other actors, for the control of the territories and the use of their natural resources [11,23–30].

Among such extractive activities, mining is one of the most historically pre valent industries in Latin America and is particularly well-developed in the Andean area [11,27,28,31–36]. Most studies addressing mining and rurality in the Andes have emphasized the overextraction and destruction of natural resources and changes to the way of life of Andean peasants and other rural inhabitants caused by deagrarianization, rural–urban pluriactivity, migration, and others, focusing on the conflictive dynamics that have arisen as extraction has intensified in recent decades [26,29,30,37–39].

Such investigations have provided valuable empirical and theoretical data on the processes occurring in recent decades; however, by examining studies that address the links between mining and Andean rural zones over a more extended period of time [32,40–42], highly contradictory trends can be observed. Today, the depletion and destruction of natural resources and accelerated changes to ways of life are the norms; yet, in other times and places, the processes driven by mining (e.g., urban growth, mining camps, and company towns) have invigorated certain agricultural activities, while at the same time weakening others. In this sense, further research that considers these relationships from a historical perspective is required to arrive at a more comprehensive understanding of how mining extractivism has led to current circumstances in rural Andean zones.

In this paper, we will consider the growth of large-scale copper mining in the Atacama Desert from the early 20th century to the present, and its connections with the agricultural transformations in neighboring zones, as a case study. Specifically, we will examine the Calama oasis, located in the Loa River basin in Northern Chile. This case study is extremely important for understanding rural transformations related to extractivism. Chile has been the world's leading producer of copper since the early 20th century [43,44]. The Loa River basin, in particular, is home to one of the largest copper-producing hubs on the planet [45]. It includes Chuquicamata, which for most of the 20th century was the world's largest copper mine [44,46]. The development of large-scale mining has driven intense urban growth, and the demand for water resources for mining, industrial, and urban consumption has increased notably [47–50]. The oases, wetlands, and tributaries of the Loa River basin have been inhabited since pre-Hispanic times by indigenous Andean groups engaged in agricultural and herding activities. While these groups' ways of life have undergone significant changes since the dawn of the colonial period, the development of large-scale copper mining and urban growth have accelerated several transformations and endowed rural spaces with new characteristics [51–55].

This article seeks to provide an understanding, through a case study, of the connections between extractivism and rural territories of the capitalist periphery during the 20th and 21st centuries. Below, we describe the case study area, then outline the research methodology. We continue with the presentation of the results in two sections: a description of the expansion of large-scale copper mining and its links to urban growth and access to water resources, and an account of the dynamics of agricultural, livestock, and land uses changes, from the early 20th century to the present, and explain how this relates to the processes addressed in the previous section. We close the article with a discussion and conclusion.

2. Case Study

The Calama oasis is situated at 2200 m above sea level (m.a.s.l.) in the Loa River basin of the hyper-arid Atacama Desert [56]. Precipitation there is extremely low, bordering on zero under 2500 m.a.s.l.; it concentrates at higher altitudes in the summer months and rises with altitude from west to east [57]. Because of this, different types of climates have been identified along the entire length of the Loa River [58], as well as a variety of ecosystem tiers, defined by the physical characteristics of their environment, the presence of water resources, and the predominant flora and fauna [59]. The Calama oasis lies within one of the basin's riparian ecosystems—areas of transition between aquatic ecosystems and the absolute desert that occur between sea level and 3000 m.a.s.l. These ecosystems depend on rivers and other watercourses to shape wetlands, oases, and ravines, which themselves sustain diverse, biodiversity-rich ecosystems. Since pre-Hispanic times, numerous interconnected human settlements have arisen around these ecosystems, and their inhabitants have engaged in agricultural activities up to the present day (in addition to the herding activities carried out in puna ecosystems above 3500 m.a.s.l.) [53,55,60,61].

In terms of political administration, the area under study was part of Bolivia until the end of the War of the Pacific (1879–1884), before being annexed by the State of Chile. At present, the area lies within the municipality of Calama, in El Loa Province, within the Antofagasta Region. Since the early 20th century, large-scale copper mining has been conducted in the area surrounding the Calama oasis, which has driven major territorial transformations, as this article attests to throughout. Figure 1 shows the location of the present-day city of Calama and the vegetative cover at the oasis, as well as the city's proximity to the main mining deposits, tailing ponds, and waste heaps.

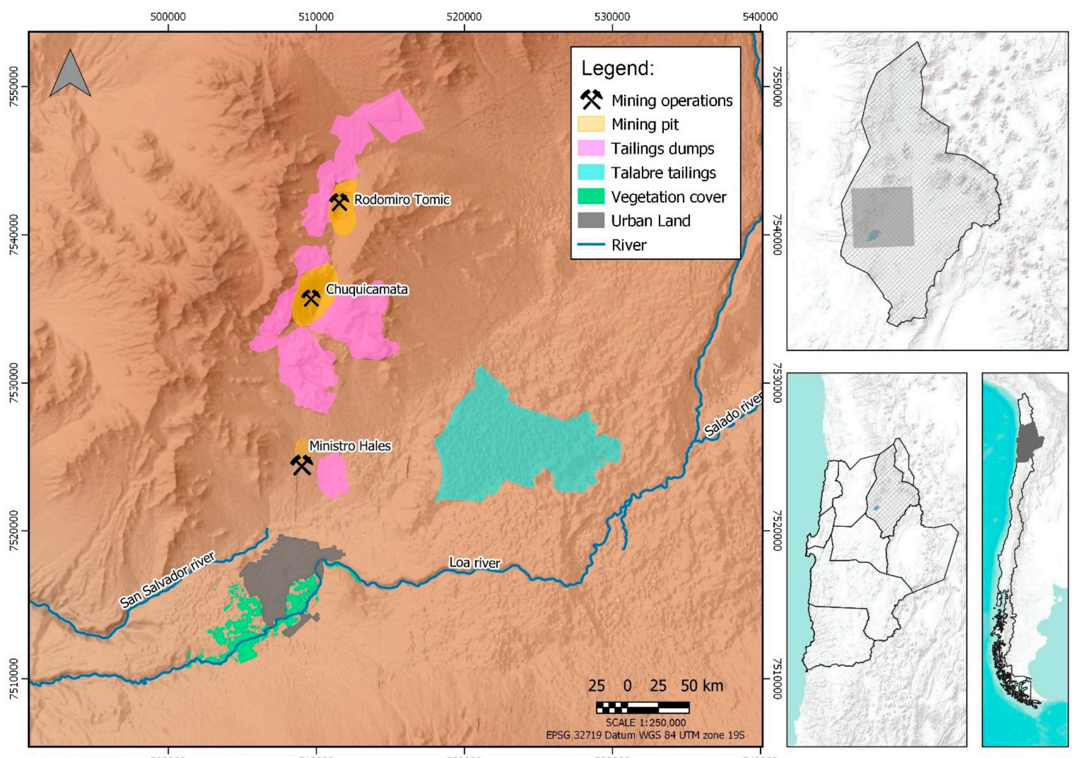


Figure 1. Location of the Calama oasis, Calama commune, Antofagasta Region, Chile, with the closest mining operations.

With regard to population, the 2017 census [62] counted 160,091 people residing in the case study area (158,487 in the city of Calama and 1604 in the rural zones of the oasis). In other words, the census reported that 97% of the total population of the municipality (165,731) resided within the case study area. In the municipality, 25% of the population (39,724 people) self-identified as indigenous, and 37,662 people said they lived in the city of Calama (95% of the indigenous population).

3. Methods

The study adopted a mixed research design that combined descriptive statistics, archival review, and bibliographical sources with ethnographic work and spatial analysis using geographic information systems. The data were grouped according to the main dimensions of interest and presented as a processual historical reconstruction, in which the different aspects were gradually concatenated.

The statistical data were used to highlight the quantitative growth of copper production in mines relevant to the case study, as well as the expansion of the urban population in the zone. Information on the mining production was compiled from the databases of the state-run Chilean Copper Commission (Comisión Chilena del Cobre, COCHILCO), where production for each copper deposit was obtained for the 1960 to 2019 period. Information on the urban population was obtained from government population and housing censes conducted between 1907 and 2017. The information was processed through a univariate descriptive analysis of frequency distributions that enabled us to assemble time series [63].

Archive and bibliographical sources were used to support the historical reconstruction of the different dimensions analyzed and are thus present throughout the article. Press files from the local newspaper, El Mercurio de Calama, were collected from the Chilean National Library for the 1968–1973 period. Furthermore, a search for bibliographical sources was conducted in different institutional repositories and the main databases of scientific journals. The data were analyzed according to central themes and coded using qualitative analysis software.

The ethnographic data aided in the historical reconstruction of the different dimensions of analysis, primarily to illuminate the agricultural transformations in the case study, based on the subjects' own experiences. The fieldwork was conducted between 2016 and 2019 in different field campaigns. Data-collection methods included participant- and nonparticipant observation, semi-structured interviews, and open-ended conversations. Fourteen semi-structured interviews were conducted with farmers (four men and ten women) and six with informants from public services and mining companies (five men and one woman). We include the ethnographic interview guideline (in Spanish) as Supplementary Material (Table S1). The data were analyzed based on the central themes and coding with qualitative analysis software.

Subsequently, agrarian transformations in the Calama oasis and the city's expansion were represented spatially, with changes in land use shown by quantifying urban growth and the reduction of vegetation cover (farmed crops and "vegas"—high Andean wetlands used for grazing animals). Analysis of the change in vegetation cover was conducted by comparing 1955 Aeroservice overflight images taken by the Chilean Military Geographical Institute (Instituto Geográfico Militar, IGM) with Landsat satellite images from 1986, 1996, 2006, and 2016. With regard to the urban area, a 2010 vector layer obtained from the government website Chile Geospatial Data Infrastructure (Infraestructura de Datos Geoespaciales de Chile, IDE) was used and compared with our own vectorization of the urban radius from 2019 and with remote-sensing images [64].

Figure 2 shows a workflow diagram of the methodological design and its execution:

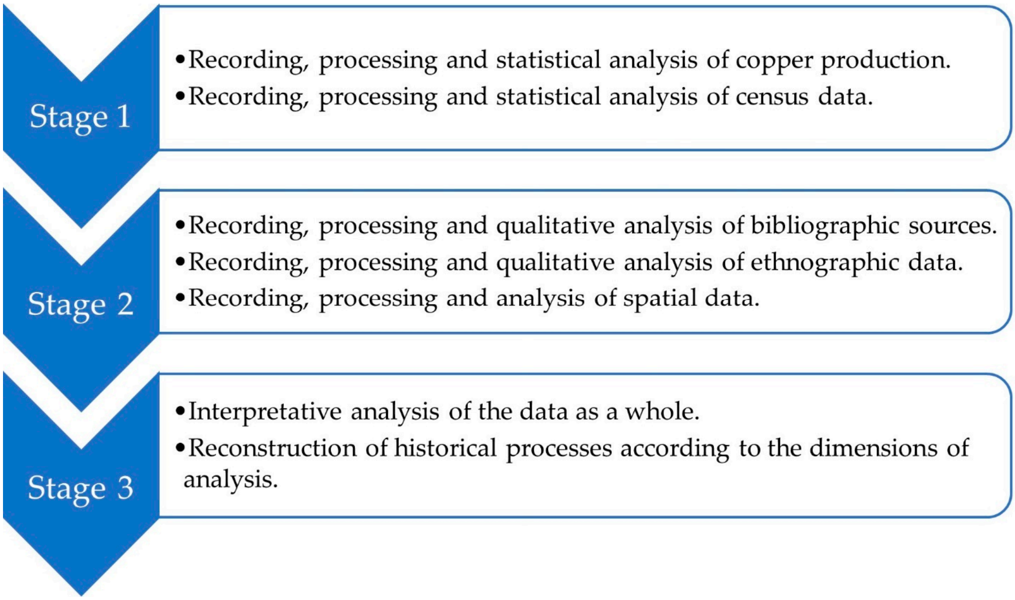


Figure 2. Workflow diagram of data recording, processing, and analysis activities.

4. The Expansion of Large-Scale Copper Mining, Urban Growth, and Access to Water Resources

This first results section characterizes the development of large-scale copper mining, which is the predominant extractive activity in the study case. This is followed by a description of the urban growth resulting from the copper expansion and then the changes in the access forms to water resources that have driven large-scale mining and urbanization. Both urban growth and transformations in water access are the two most essential processes derived from the expansion of extractivism and are crucial to understanding the changes in agricultural and livestock activities and land use in the Calama oasis.

4.1. Development of Large-Scale Copper Mining

In 1915, 20 km from what was then the town of Calama, the US-owned Chile Exploration Company (Chilex) opened the Chuquicamata copper mine. Before then, the area had been mined by individual miners, called pirquineros, and small and medium-sized companies. In addition to opening up the deposit, Chilex built a series of infrastructure works, including a copper oxide treatment plant, an internal railway line to transport the ore, a thermoelectric plant on the coast and a transmission line to the mine, an ore processing plant, a camp to house 15,000 miners and their families, and a network of intakes and pipes for extracting water from the upper reaches of the Loa River basin and transporting it to the mining operations and camp. When it opened, Chuquicamata became the largest copper extraction operation in Chile, and indeed the world, and remained so for most of the 20th century [44,46,65].

During the first half of the 20th century, Chuquicamata's production grew steadily, and by the end of the 1950s, it accounted for 57% of all copper extracted in Chile [66]. From 1950 to 1970, modernization projects were implemented in the large-scale copper mining industry in Chile and throughout the world [67]. In Chuquicamata, a new sulfur plant was opened, along with a modern housing development for workers, many industrial processes were automated, and machinery was updated. In addition, a new refinery was opened, and new water intakes and infrastructure were built, alongside other innovations [47,49,67].

The mine also introduced new workforce management policies, which included moving some of its workforce to the city of Calama [67]. This modernization process occurred at a time of internal upheaval in Chile that included intense labor disputes at different mines and an environment of intense public debate around the international control of Chile's large-scale copper mining sector [44,46,67].

Despite the above-mentioned initiatives, production did not increase as much as expected. The large-scale copper mining industry, and Chuquicamata in particular, remained at the center of public debate in Chile. Between 1966 and 1969, during the administration of Christian Democratic President Eduardo Frei Montalva (1964–1970), the Chilean State acquired a majority interest in the country's large-scale copper mining sector. Subsequently, in 1971, the government of socialist President Salvador Allende Gossens (1970–1973) nationalized the industry, placing all operations under the ownership of the state-owned National Copper Corporation (Corporación Nacional de Cobre, CODELCO) [44,46,67]. As the leading operation in the country, Chuquicamata played a strategic role in the political project of Allende's government [68,69].

In 1973, a military coup ushered in the civil–military dictatorship led by Augusto Pinochet (1973–1989). The regime implemented a series of neoliberal policies that included the privatization of natural resources, public enterprises, and essential services, as well as the liberalization of markets and the movement of capital [70–72]. Nevertheless, aware of the role that large-scale mining played in the national economy and the revenue it generated for the functioning of the Chilean State, particularly its Armed Forces, Pinochet did not privatize the large mines that had been nationalized in 1971. The regime limited itself to designing the institutional framework that ultimately enabled the expansion of large-scale private mining from 1990 onward under successive democratic neoliberal governments [73,74]. As such, Chuquicamata remains the property of the Chilean State to this day.

Prior to 1990, Chuquicamata was the only large-scale copper mine in the Loa River basin. It was later joined by the state-owned Radomiro Tomic (1995) and Ministro Hales (2013) mines and the public–private El Abra (1996), all situated in the municipality of Calama. These new investments intensified copper extraction in the area, with the production of the mineral rising from 681,000 metric tons (MT) in 1990 to 885,000 MT in 2019. Production peaked in 2004 at 1.2 million MT [75].

An important aspect for understanding the territorial processes associated with copper mining expansion over time is that, regardless of the political orientation of any given administration, in operational terms, management of the mines has focused on constantly increasing production [76–78]. While accelerations and slowdowns have occurred at different times in the evolution of copper production in the Loa River basin throughout the 1960–2019 period (Figure 3), the overall trend shows an increase in extractive capacity, most notably in the 1975–1990 and 1995–2005 cycles.

4.2. Urban Growth

While small and medium-scale mining activity in the Chuquicamata area prior to 1915 had drawn workers from other parts of Chile [65] and Bolivia [79], the scale of the Chilex operation significantly increased the urban population of the Antofagasta Region [47,80]. It must also be considered that the construction of a camp for 15,000 people rapidly reconfigured the demographics and functioning of the territory [81].

The camp's population grew steadily from the beginning of mining operations at Chuquicamata until the mid-20th century (Figure 4), before the number of residents stabilized at around 24,000 in the 1952–1960 inter-census period. From then onwards, the population gradually decreased until the 2002 census. It should be noted that the camp was closed in 2007, and its population relocated to Calama, owing to the expansion of productive operations [81]. Meanwhile, the population of the city of Calama also rose with the opening of Chilex operations, but at a different pace than the camp. The city's population increased slowly until the 1940s, at which time it began to rise much more sharply; it has continued to do so up to the present. The 2017 census reported 158,487 people living in the city.

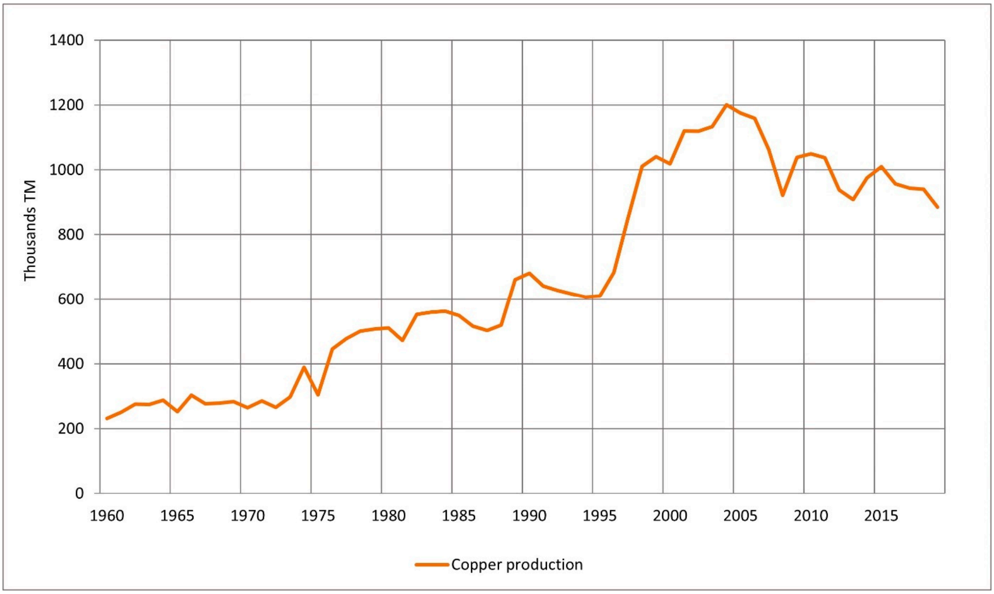


Figure 3. Production of large copper mining in the Loa River basin in thousands TM.

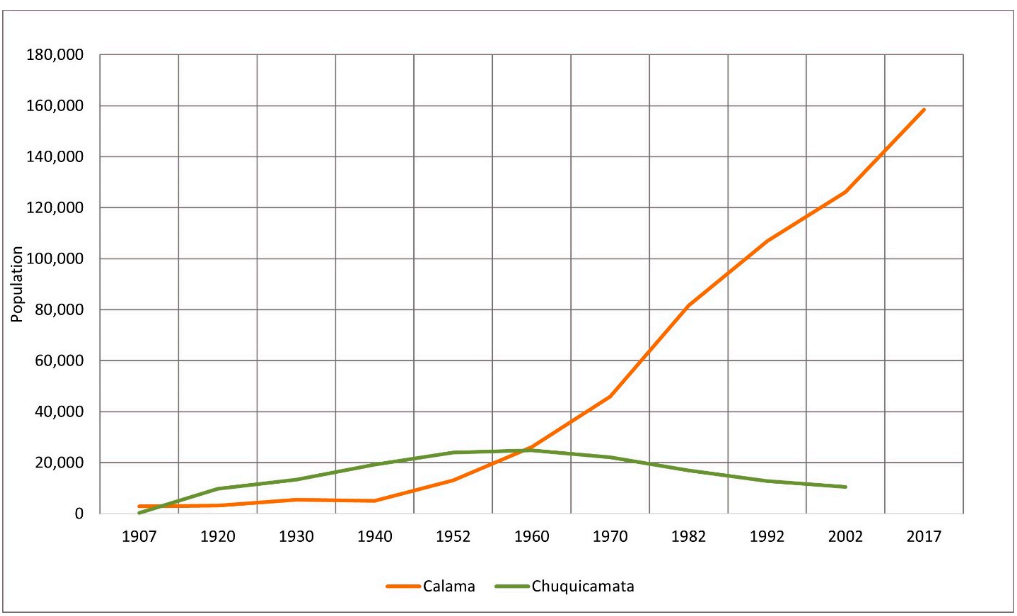


Figure 4. Population growth in the cities of Calama and Chuquicamata.

Calama has experienced two periods of urban growth, both linked directly to corporate policies introduced at the Chuquicamata mine. The corporate modernization and productive expansion policies that were favored from 1950 to 1970 included moving workers and their families to Calama and limiting the population of the camp. By 1970, 32% of the Chuquicamata workforce resided in Calama [67], where the company had built several housing developments for its workers and their families [81–84].

Another factor in Calama's growth was not linked directly to mining but caused by the attractive employment opportunities in sectors of the economy associated with mining expansion and urban growth. A significant proportion of new migrants have been relatively unskilled individuals working in low-paying jobs, and many have erected their own homes informally on the outskirts of the city, in areas without essential services [85–88].

In light of the social problems and impacts on quality of life associated with the above, the Chilean State has instituted several programs related to housing regularization, formal construction, essential service installation, and urbanization in general. From the 1960s to the 1980s, these programs essentially relied on government action and pressure from residents [89,90]. From the 1990s to the present, however, urban growth projects have sought to implement public services in collaboration with large-scale public and private mining concerns in the area [91,92]. Nevertheless, critiques about the poor quality of life in the city, and the impact copper mining has had on it, have been at the center of social mobilizations in recent years [93].

Lastly, growth in the city of Calama, whether through state action or corporate policy, has extended the city into nearby agricultural lands and vegas [64,94–96]. At certain moments, this has led to disputes among farmers, authorities, and other stakeholders [97–99]. According to our ethnographic records, this situation is ongoing, with housing development prioritized over agricultural development and care of the vegas in the Calama oasis. In the opinion of those interviewed, this has been one of the leading causes of the deagrarianization process in recent decades.

4.3. The Access to Water Resources

Since the late 19th century, the demand for water from the Loa River has grown considerably with the expansion of the nitrate industry in the region, the building of the Antofagasta–Bolivia railway, and the growing demand for drinking water for mining camps and cities [48,100]. Water resource extraction and the privatization of water rights rose sharply from 1915 onward with the development of large-scale copper mining and the accompanying urban expansion; complex systems of intakes, pipes, and storage ponds were also built along the basin [47–50,101].

Due to increasing demand, between 1888 and 1920, a series of local-regional regulatory instruments were developed to govern the ownership and usage of water from the Loa River [100,102]. When the Chilean State began enacting national water codes (in 1951, 1967, and 1981), water management came under the purview of these laws. In both local-regional and national regulations, agricultural and livestock activities in general, and smallholder agriculture in particular, have been negatively impacted [50,103,104].

The 1920 regulation prioritized the nitrate industry, the railway, urban consumption, and the copper industry; at the same time, irrigation was allocated less water than it was using. The studies underpinning the regulation [102] estimated that Calama's irrigation canals captured an average 3 L/s per hectare (ha), which was used for irrigating crops and vegas. Nevertheless, some argued that watering the vegas was a waste of resources [102]; this ignored their role in grazing livestock, which was primarily carried out by indigenous peasants. The regulation ultimately authorized 1.5 to 2 L/s per ha for the irrigation of crops and expressly prohibited the irrigation of vegas. In contrast, 500 L/s was reserved for potable water and the railway, 400 L/s for nitrate production, and 300 L/s for industrial use and ore processing.

The national water codes of 1951 and 1967 granted the Chilean State significant regulatory powers, with the 1967 code strengthening its expropriation authority over all private water rights [105]. Under the new regulations, new water rights in the Loa River basin were allocated for large-scale copper mining and urban consumption, and water extraction increased with new intakes, pipes, holding ponds, and a very large reservoir [47,50,101]. During these years, Calama's farmers complained to the authorities that the works were impairing their irrigation capacity in the oasis and threatening agricultural activity [106]. Nevertheless, as the following section shows, at the same time—and perhaps in an attempt to counteract the above-described effects—the State implemented several agricultural development projects in the area under study.

The Water Code of 1981 was one of several neoliberal policies implemented by the Pinochet-led dictatorship (1973–1989) [105,107]. Essentially, it strengthened private ownership of water resources and sought to establish a market for water rights by separating the ownership of land from the ownership of water. The Code was implemented in the Loa River basin between 1982 and 1984, granting individual private ownership to farmers in the basin's main agricultural sectors, including the Calama oasis (the other localities were Quillagua, Chiu Chiu, and Lasana) [50,108,109]. The goal was to define specific ownership rights for farmers, thereby freeing up surplus water for mining and potable uses. In fact, the report supporting the regulation of water rights explicitly stated that the priorities for allocation were, in the first place, potable water, followed by the extractive industry, and, thirdly, irrigation [110]. Furthermore, the report argued that the irrigation of vegas should be restricted [108,109]. This is a common practice in the Andes, but states have usually kept it hidden [111]. Thus, when farmers' individual water rights were registered, less water was recorded than was actually used. Technical and administrative staff did not count the irrigation of fallow lands or vegas and employed deception and other tricks (telling farmers that irrigation water would have to be paid for in the future), as well as confusion (farmers had no way of translating their traditional irrigation practices into liters per second) and fear (as this occurred during the dictatorship, some farmers reported that they would not have been able to oppose the policy) [50,108,109].

The Ley Indígena (Indigenous Law) of 1993 (19,253) enabled indigenous associations and communities, as well as indigenous individuals, to register water rights in their own name and use funds provided under the law to purchase them on the market. In this way, the farmers of the Calama oasis have been able to recover or retain some of the water they were legally dispossessed of when the 1981 code was implemented [112]. However, because of the multiple surface and groundwater rights granted to the mining industry and potable water companies since the Water Code has been in force, in 2000, Chile's National Water Authority (Dirección General de Agua, DGA) declared the surface water of the Loa River exhausted [113].

In retrospect, the dynamic described has generated different episodes of water dispossession and disputes since the emergence of large-scale copper mining to the present, with the involvement of several main stakeholders—indigenous farmers and irrigators in the Loa basin, Chile's large-scale copper mining companies, potable water companies, and the Chilean State [50,52,54,104]. One of the first water disputes documented in relation to Chuquicamata occurred near Calama before 1920 when a landowner in the city accused Chilex of building a pipe to steal water that he owned. Only after the court ruled against the company did it stop extracting water [114].

5. Agrarian Change and Deagrarianization

This second section of results characterizes the agricultural, livestock, and land-use changes in the Calama oasis. It is shown how these transformations are directly connected to the expansion of extractivism and its derived dynamics, presented in the previous section.

5.1. Agricultural and Livestock Activities before the Development of Large-Scale Copper Mining

During the colonial period (16th–18th century), the Calama oasis maintained an agrarian structure that, with some changes over time, remained essentially the same until the early years of the 20th century [48,61,115,116]. Overall, there were two main economic sectors in the area, which coexisted and had dealings with one another. On the one hand, were the large-scale farming estates that occupied the most arable lands. They focused on growing alfalfa to be sold as forage and leased space for grazing livestock (mainly cattle in transit). The owners of these lands had removed themselves from direct production and thus required day laborers. They also had business and mining investments in the region and constituted a local bourgeoise with multiple interests. Their operations had ties with agricultural markets and the circulation of merchandise in general. This kind of operation was under the control of the non-Indigenous population: first, Spanish colonial agents; then, beginning in the early 19th century, citizens of the newly- formed nations of Bolivia, Chile, and Argentina, as well as immigrants from other European and Asian countries (e.g., Spain, Croatia, Syria). In contrast, the other type of operation present in the Calama oasis corresponded to smallholdings situated on the land further from town; they had less potential for commercial agriculture because of the size of the farms and the presence of vegas. These farmers grew alfalfa and corn and grazed sheep, llamas, goats, and, to a lesser extent, cattle on the vegas. They consumed what they produced and occasionally sold or traded with other indigenous farmers or groups. The family provided the workforce, and some members also found work as salaried workers (full or part-time) on the larger agricultural estates, in businesses, or in the area's mining activities.

Ten years before Chilex launched its operation, Risopatrón [117] wrote that Calama's commercial agriculture had great growth potential, as there was enough demand for agricultural products at the borax mines of Ascotán and the small mining operations of El Abra and Chuquicamata. In 1913, just two years before Chilex began operations, Bowman [118] noted that there was significant agricultural activity at the Calama oasis, oriented mainly toward the production of alfalfa as forage for the livestock used for hauling (mules) or food (cattle) at the nitrate mines. In fact, he highlighted Calama as the principal forage production center in northern Chile.

In addition to the above, some sources indicate that, before Chilex began its operations, the indigenous peasant population of the Loa River basin increasingly participated in the labor market: as salaried employees in the mining industry, working at higher altitudes (sulfur, borax, and other mines) [119], in small-and medium-scale copper operations that were working the Chuquicamata deposit, and in the Caracoles silver mine (near Calama). This meant that agricultural and livestock-raising activities were already becoming less critical for indigenous subsistence [61,116].

5.2. The First Half of the 20th Century: Urban-Extractive Food Markets and Agricultural and Livestock Dynamism

With large-scale copper mining occurring from 1915 onward, and the nitrate industry in crisis throughout the 1920s [120], the agricultural activities of the Calama oasis became more progressively linked with copper mining in the area and its attendant urban growth. These have become the main factors in explaining its development to date.

In the 1920s, the agricultural system was simultaneously connected to the declining nitrate industry and the expanding large-scale copper mining sector. At the end of that decade, some agricultural dynamics linked to nitrate operations and their markets remained. Rudolph [48] mentions 1780 ha under cultivation, primarily planted to alfalfa, and cattle, in transit from Argentina to the nitrate offices, grazing on the extensive pasturelands; there is also mention of sheep and llamas, which would have provided meat and wool to the local population, grazing on the vegas. The author also notes that care of the crops and herding were tasks that fell primarily to women. Based on this information, we can infer that the male indigenous population was mainly employed in non-agricultural occupations, such as mining or associated activities. At the time, the main hub that attracted workers and offered employment was the Chuquicamata mine, which employed 8000 workers, who, along with their families, accounted for the 18,000 people living at the camp.

From the 1930s to the end of the 1960s, driven by the demand for food from growing urban centers (the Chuquicamata camp and city of Calama), land ownership at the oasis became concentrated. Sanhueza and Gundermann [116] report that, from the late 1920s, the number of small family-run farms further from town and those pasturing their herds on the vegas dropped. At the same time, more and more land became privatized, and the large estates producing alfalfa and raising cattle and sheep expanded in size, selling their products in the city of Calama and the Chuquicamata camp. These so-called "fincas" dominated the rural space of the Calama oasis until the early 1970s [121]. Their existence explains why the area planted to alfalfa increased by more than 1000 ha in Loa Province between 1935 and 1964 [51]. Their links with local urban markets enlivened these operations, and their base of paid labor made them an employment hub for indigenous migrants from rural towns in the Loa interior (such as Ayquina, Turi, Cupo, Caspana, Toconce, and others) who came to the city of Calama. According to some informants, for those who did not have the contacts or knowledge to enable them to obtain higher-paid employment in the mines or in the city, working on the fincas was one of the more feasible options. To carry out their agricultural and livestock activities, the fincas combined salaried employment (seasonal and year-round) with traditional work relationships that did not involve the payment of a wage [51].

Our ethnographic records and other sources [90] reveal that family-run farming activities continued in places further from the city, albeit in a lesser fashion. Based on the interviews conducted, we identified two crucial differences in how they operated in relation to the previous period: (a) farmers hired themselves out more (to fincas, urban employment, and mining), and (b) the diminishing use of the vegas for grazing, owing to a lack of labor and fewer water resources available to irrigate these seasonal wetlands.

In summary, while, on the one hand, Calama's population had been growing since the 1940s, on the other, agricultural activity on the fincas and the persistence of family-based agriculture from the 1930s to the late 1960s kept the land around the city predominantly in agricultural use (Figure 5).

Figure 5. Aerial view of Calama in 1966. Source: National Historical Museum Collection (Author: Anonymous).

5.3. The Second Half of the 20th Century to the Present: Changes in the Agricultural and Livestock System and the Deagrarianization

The land ownership structure that has been described above changed significantly from the late 1960s onwards. At the local level, it should be noted that agricultural activity on the fincas slowed down as alfalfa sales dropped significantly, along with the demand for forage for livestock [122]. The cattle that had been imported from Argentina were being replaced by imports of butchered meat [123], which weakened the underlying economic dynamic of the fincas.

At the national level, it is important to consider that an Agrarian Reform (Law 16,640) was enacted between 1967 and 1973 in Chile. The law sought to liquidate large agricultural estates owned by landlords and redistribute the land to the peasantry, in addition to modernizing agricultural and livestock production and overcoming the marginalization and poverty that affected the country's rural peasants and laborers. To accomplish this, the government introduced organization and training programs for peasants, invested in equipment and technology, and provided technical assistance. Large holdings were also expropriated, and the Asentamientos Campesinos (peasants' settlements) were formed (a transitory institution formed after an expropriation that functioned as a collective production unit managed by peasants with government assistance) [124].

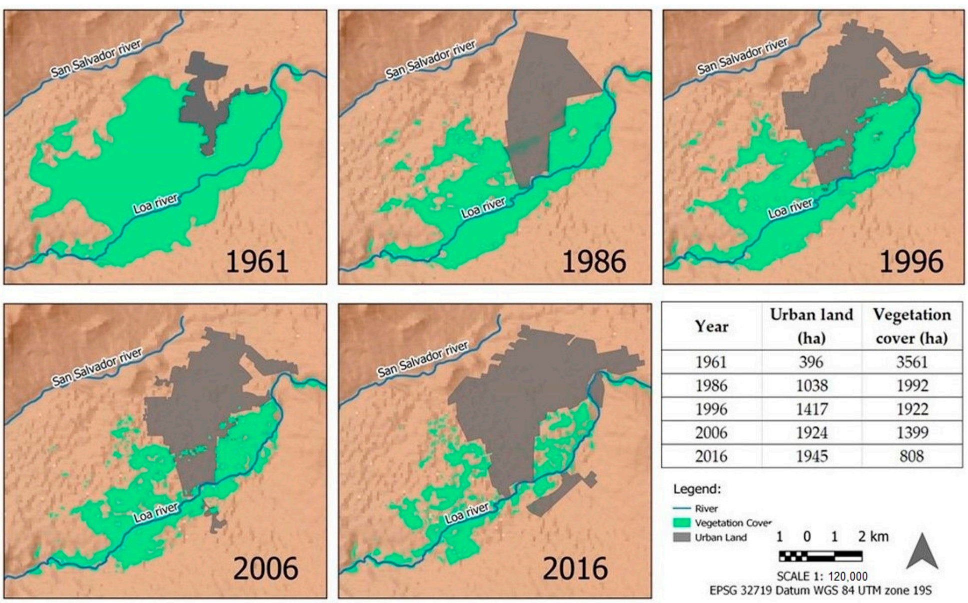
In the study area, during Frei Montalva's administration (1964–1970), different initiatives were put forward that sought to organize and train peasants, improve irrigation infrastructure, formalize the ownership of small operations, and provide technical and financial assistance and technological support [123,125–127]. During the administration of Allende Gossens (1970–1973), in addition to projects concordant with previous initiatives [88,95,128–130], the largest fincas in the rural areas of the oasis were expropriated [131]. The government argued that the expropriation was justified, as productive activities on the estates had virtually stopped [132].

After the 1973 coup, the dictatorship ushered in a nationwide neoliberal counter-reform that instituted a series of measures, such as the restitution of expropriated properties, the division, sale, and auction of 'settlements' as individual parcels, the liberalization of the land market, and the creation of a water market. This fostered the emergence of small and medium-sized agricultural enterprises and large, high-tech capitalist operations linked to the global market [124,133]. In the Calama oasis, however, the counter-reform acquired a different expression. According to our ethnographic records and other sources [90,134], the peasant 'settlements' were indeed broken down into individual parcels; however, in general, the fincas were not reconstituted, nor were the large agribusinesses formed as planned. We argue that owing to the crisis that had been occurring in the alfalfa market before the Agrarian Reform and the limitations on introducing other crops in the area in question due to the salinity of the water [121,135], those who had owned the fincas moved their capital to other sectors of the economy. When they were given new land or regained possession of their former estates, they sold them to housing developers. Even before expropriations began, owners of the fincas had already been selling their land to developers [94]. Several informants spoke of places in the city of Calama that had formerly been part of the fincas and were now urbanized.

In the 1980s, state investment and development in peasant agriculture decreased. Although there were different initiatives in the Calama oasis [90], those interviewed perceived that state support was reduced and insufficient. Thus, during this time of intense mining expansion, limited access to irrigation water, increased urban encroachment, and lower public investment supporting peasant agriculture, the family smallholdings that had resulted from the parceling of settlements became fewer in the process of deagrarianization that can still be observed today. While, in the 1920s, an estimated 1780 ha of land were under cultivation in the area [48,102], by the end of the 1970s, that area had dropped to just 1112 ha [110], and, by 2006, to 418 ha [135].

As the fieldwork for this case study confirmed, in agreement with Mondaca and Ogalde [90], since 1990, public investment in programs serving peasants in Calama has increased (in the form of loans, subsidies, training, provision of inputs and equipment, animal sanitization, improvements to irrigation infrastructure, and support for non-agricultural enterprises). Organizations participating in the implementation of these programs include the Agricultural Development Institute (Instituto de Desarrollo Agropecuario, INDAP), the Agricultural and Livestock Service (Servicio Agrícola y Ganadero, SAG), and the National Irrigation Commission (Comisión Nacional de Riego, CNR). Chile's National Indigenous Development Corporation (Corporación Nacional de Desarrollo Indígena, CONADI) has also provided funding for the acquisition of water rights and for improving irrigation infrastructure. These activities have occurred in a context in which the historic inhabitants of the oasis have been forming indigenous communities and associations within the framework of the Indigenous Law of 1993 (19,253). These new entities coexist and intersect with older organizations such as neighborhood associations, farmer and irrigator associations, sports clubs, women's centers, and others [90,99,112,136]. These projects have revitalized some agricultural activities and irrigation in certain parts of the oasis; however, they have not affected the forces exerting pressure to deagrarianize, and thus the process continues.

Areas with vegetation cover steadily diminished as the city expanded. From 1961 to 2016, the urban footprint increased by 1549 ha, while vegetation cover fell by 2753 ha (Figure 6). This is because the city has directly encroached upon those areas and because of the abandonment of agricultural activities and the limited irrigation of the vegas.



Year	Urban land (ha)	Vegetation cover (ha)
1961	396	3561
1986	1038	1992
1996	1417	1922
2006	1924	1399
2016	1945	808

Figure 6. Evolution of urban land and vegetation cover in the Calama oasis (1961–2016).

During the ethnographic work conducted, researchers recorded that there are still some smallholder family farms operating in the Calama oasis today that grow alfalfa and corn (for family use and sale) and raise livestock (for family use and occasional sale). Sheep are the main livestock, although there are also goats, llamas, some horses, and smaller animals (pigs and rabbits) present. Families provide the labor for all of these agricultural and livestock activities. In regard to livestock, the vegas are no longer used for grazing; animals are instead rotated among corrals. This is because of the limited workforce available, the small number of animals, and the poor nutritional quality of vegetation in the vegas. It should be noted that many family members engaging in farming activities do not do so full time, especially the younger generations, who are inclined to seek out salaried work or self-employment in cities (construction, service, retail, etc.) and, to a lesser degree, in industry or mining operations. In fact, for some families living in rural areas, agricultural and livestock activities play a marginal or even nonexistent role in their livelihood.

As for the sale of agricultural products, our ethnographic data shows that alfalfa is sold directly from the farms to other peasant farmers in the area of study or those in other rural areas of the Loa interior. Some farmers sell alfalfa to the Calama Rodeo Club. Corn is often sold directly from the farm as well, in small quantities to intermediaries. Occasionally, an entire field of corn is sold to a single buyer who will arrive with laborers to harvest the crop.

The general perception among interviewees is that agriculture has been diminishing over time and is presently extremely precarious. According to testimonials based on interviewee experiences, the following processes have been causing this situation:

- Urban sprawl into farmlands and vegas, as well as non-agricultural use of rural spaces, the latter by longstanding property owners who have stopped practicing agriculture and new owners who purchased their properties for other purposes (e.g., auto-mechanic shops, parking, tourism).
- Fragmentation of agricultural lands through inheritance, which makes it difficult to practice certain activities because of the extremely small plots.
- The younger generation's relative lack of interest in farming and raising livestock, as they can obtain higher income from salaried employment or as independent workers in the city, in industry, or the mines. At the same time, family operations cannot afford to hire outside help.
- Lower quality and quantity of water resources owing to urban expansion and mining growth, which drives higher water extraction, causes water pollution, and concentrates water rights outside of the agricultural sector.
- Little regulation or state control of mining, water use, land use planning, and urban growth, in parallel with inadequate support for peasant agriculture.

6. Discussion and Conclusions

The results presented here show how the Calama oasis is a paradigmatic study case for understanding the transformations occurring in rural territories near extractive operations of global importance. The area has undergone a series of agricultural, livestock, and land-use changes related to urbanization and the privatization of natural resources. The dynamics in question do not follow a unilinear trend over time but vary historically and are explained by the confluence of processes at different levels (macro–micro, global–local) and by the intersection of ecological, economic, political, and cultural dimensions. In the same way that it is possible to observe common trends in other rural territories and spaces affected by extractivism, there are specific dynamics that can only be understood in relation to the particular history of the study case. Therefore, research on these issues should be guided by theoretical frameworks and methodological approaches that seek to understand the different scales and dimensions of analysis that interact in a particular space.

The case study shows the links that have existed between extractivism and the growth of urban centers in Latin America [137], and particularly of the close connection between mining and urban expansion in the southcentral Andes [138,139]. The urbanization of the Calama oasis has been driven by three mechanisms: (a) corporate policies focused on increased production, which involves city growth; (b) informal growth of the city perimeter due to unplanned settlement by people attracted there; and (c) urbanization promoted by the State with the aim of regularizing and installing essential services in peripheral zones of the city that developed informally.

The growth of the mining industry in the Loa River basin, and the expansion of the city of Calama and other regional urban centers, led to a higher demand for water resources and labor over time. In this regard, as observed in other parts of the Andes [26,29,30,37–39], mining extractivism has driven territorial transformations that are accompanied by the dispossession and destruction of natural resources, the proletarianization of urban and mining occupations, and intense transformations in the ways of life of peasants and other rural inhabitants. Thus, significant changes in land use occurred in the rural spaces of the Calama oasis, tending in recent decades towards the urbanization of the rural space, urban–rural pluriactivity, and a deagrarianized way of life.

Nevertheless, analysis of the agricultural dynamics of the case study area from a long-term perspective shows that, along with the above processes, and as in other parts of the southcentral Andes [32,40], at certain times, the mining industry, its camps, and cities have strengthened the position of stakeholders in the agricultural system by creating demand for their products. In the Calama oasis, it was primarily the large landowners operating extensive alfalfa-producing estates who wasted no time moving their capital to other sectors of the economy when profitability dropped.

The indigenous peasantry, despite receiving state support at certain times, has become progressively weakened. During specific periods, supportive public actions and the farmers' own appeals competed with other public policies in force at the same time—the ongoing support for copper extraction, the privatization of water resources, the limits on irrigation, and the promotion of urban growth—to lessen their potential impacts. Despite all of this, however, the peasants are virtually the only actors today that are sustaining the now-diminished agricultural activities at the oasis. While these activities continue to play a role in providing livelihoods, they also endure because they are entangled with the farmers' traditional land-based way of life. We can thus see the intersection of different scales of economic and political processes in how certain forms of land use are configured and vary over time, from the international context to national policies and the dynamics unique to the territory and its inhabitants. Despite the intense deagrarianization of recent decades, the urban–agrarian linkage is still present in certain parts of the study area (Figure 7).

Figure 7. Agricultural lands adjoining urban lands in Calama in 2019. Source: the authors.

Finally, the data analyzed show that any government policies applied locally that seek to halt deagrarianization and promote agricultural and livestock activities will have a limited scope because the fundamental processes that are negatively affecting these activities correspond to national and global economic and political factors. In this sense, Chile currently has a unique opportunity to try to turn these aspects around. During the years 2021 and 2022, a popularly elected body will discuss a new constitution. Among the central issues of public debate, extractivism and the management of natural resources have occupied a prominent role. Thus, if the new institutional framework establishes effective power mechanisms for local populations to define the development strategies of their territories and the use of their natural resources, it is feasible that subsequent public policies of local scope will increase the degree of their effectiveness in a new, more favorable economic and political context.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/land10111262/s1, Table S1: Ethnographic interview guideline (in Spanish).

Author Contributions: Conceptualization, M.C.-S. and M.P.; methodology, M.C.-S., F.V. and M.P.; validation, M.C.-S., M.P. and O.M.-R.; formal analysis, M.C.-S. and F.V.; investigation, M.C.-S., F.V., P.H. and E.E.; resources, M.P.; data curation, M.C.-S. and F.V.; writing—original draft preparation, M.C.-S.; writing—review and editing, M.C.-S., M.P. and O.M.-R.; visualization, M.C.-S. and F.V.; supervision, M.P. and M.C.-S.; project administration, M.P.; funding acquisition, M.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Universidad de Tarapacá, Proyecto UTA Mayor N° 5798-21.

Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Ethics Committee of Universidad de Tarapacá (protocol code 12/2020, approved 4 May 2020).

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

Data Availability Statement: The copper production data are available in COCHILCO at www.cochilco.cl, accessed 4 April 2016 and 2 March 2020. Population data were obtained in person from the Documentation Center of the National Institute of Statistics in Santiago, Chile. Some population data are available at www.ine.cl, accessed 19 January 2018. The ethnographic data are not publicly available due to ethical restrictions. The archival data are not publicly available due to copyright restrictions. Some geospatial data are not publicly available due to copyright restrictions, while others are available in IDE at www.ide.cl, accessed 1 March 2021.

Acknowledgments: We acknowledge support from Agencia Nacional de Investigación y Desarrollo (ANID), Fondecyt 1201527. M.C.-S. acknowledge support from Agencia Nacional de Investigación y Desarrollo/Scholarship Program/Doctorado Nacional 2019–21190475. F.V. acknowledge support from Agencia Nacional de Investigación y Desarrollo/Scholarship Program/Doctorado Nacional 2021–21211935. M.P. and M.C.-S. thank the Center for Intercultural and Indigenous Research (ANID, Fondap 15110006). The authors thank the informants interviewed.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study, in the collection, analyses, or interpretation of data, in the writing of the manuscript, or in the decision to publish the results.

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Which Polish Cities Sprawl the Most

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Abstract: Spatial transformations stemming from urban sprawl are evident not only in the USA or Western Europe but also in Central and Eastern Europe, including Poland. Urban sprawl materialises mostly in land-cover and land-use change involving an increase in the proportion of urbanised areas and discontinuous urban fabric in the total area. The paper's objective was to identify the degree of urban sprawl based on the area of discontinuous urban fabric. The spatial analysis was aimed at finding differences in land-cover ratios by individual urbanised land categories. The analysed data for 2006, 2012, and 2018 were retrieved from the Urban Atlas. The method employed was NUASI (normalised Urban Atlas sprawl indicator). A series of computations revealed that urban sprawl is found in Poland as well. Changes caused by the increase in the discontinuous urban fabric in the total urban fabric were the most pronounced from 2006 to 2012. From 2012 to 2018, the pace of the increase stabilised, but its dynamics declined. The study demonstrated a strong spatial variability of the indicator. Urban sprawl was found to be the most intense in southern and southeastern Poland.

Keywords: urban sprawl; discontinuous urban fabric; suburbanisation; functional urban area

Citation: Renata, R.-C.; Barbara, C.; Andrzej, S. Which Polish Cities Sprawl the Most. *Land* **2021**, *10*, 1291. https://doi.org/10.3390/land10121291

Academic Editors: Carmen Delgado Viñas and María L. Gómez-Moreno

Received: 26 October 2021
Accepted: 23 November 2021
Published: 25 November 2021

1. Introduction

Suburbanisation dominates the development of most global cities today [1,2]. Klausen and Røe [3] even claim that 'the world is increasingly urban, and the urban world is increasingly suburban'. The term suburbanisation has come to be used to refer to the development of a city beyond its administrative boundaries [4,5]. It is also defined as a centrifugal diffusion phenomenon of urban agglomeration, which leads to the development of the suburbs [6]. Symptoms of suburbanisation grew in Poland in the early nineteen nineties after the country abandoned a command economy, including central spatial planning, in 1989 and moved towards the free market and local-authority-based spatial planning. The second wave of suburbanisation in Poland from 2006 to 2012 could have been driven by the membership of Poland in the European Union.

In demographic terms, suburbanisation is most often recognised as a process leading to a significant increase in the population on the urban agglomeration fringe compared to the number of residents in the city core (CC) [7–9]. This specific process is often referred to as a preliminary stage or residential-area suburbanisation because people tend to choose fringes rather than the core to live at this point [10]. The next stage of suburbanisation caused by the increasing distance to commerce and the workplace is economic changes. Businesses and services move from the CC to suburban areas (economic suburbanisation, commerce suburbanisation) [11,12]. As a result, the core grows depopulated and bereft of its previous functions, which move outside city limits [13,14]. Furthermore, suburbanisation poses a challenge for transport in suburban areas that is the direst in the best-accessible places [15].

Demographic and economic transformations are entwined with spatial and functional changes. These shifts are manifested in changed suburban land cover and use, mostly in increasingly urbanised, mainly residential, areas in the land-cover and -use structure. It comes at the expense of open-space areas, usually agricultural land. Such spatial policy bolsters land-management and -use chaos, particularly regarding the situation of new buildings [13]. Wilkosz-Mamcarczyk, Olczak, and Prus [16] pointed out that Polish rural areas adjacent to most large cities are often spatially chaotic. Majewska et al. [17] compared Polish suburban building arrangements to a badly played Tetris game and Grochowski [18] to scattered confetti. The urban planning chaos contributes to the Tetris-like development regardless of soil fertility and lost agricultural resources. Urban pressure fosters an increase in farmland value [19]. Urban pressure may seem like a bargain for farmers in the short term. They can sell peripheral parcels of their holdings. Real estate developers pay high prices for land to build monofunctional residential neighbourhoods. Spatial planning that is focused solely on profit may have poor social consequences and cause spatial problems.

These processes drive urban sprawl, which is a particularly adverse effect of suburbanisation transformations. There is no common consensus on the definition of 'sprawl' [20–23]. The definition adopted by each researcher depends on the research perspective [20]. According to Wassmer [24], Earle Draper of the Tennessee Valley Authority first used the term' sprawl' at a national conference of planners in 1937. Draper referred to sprawl as an ugly and uneconomic change of the countryside. Urban sprawl is related to low-density, dispersed, or discontinuous ('leapfrog') growth of urban fabric and isolation of land uses accompanied by a series of environmental and socioeconomic issues [25–27]. Researchers [22,28–30] claim that urban sprawl is a process related to chaotic, dynamic, and uncontrolled changes in the spatial structure of suburban areas, believed to be caused mainly by insufficient urban planning regulations. Harvey and Clark [31], as well as Abidin, Zamani, and Aliman [32] claimed that this phenomenon manifests itself in the development of low-density buildings, ribbon development, or the leapfrog characteristic. Chettry and Surawar [33] reported that scattered development should also be considered an urban sprawl type. The Polish spatial planning system still lacks tools for coordinating spatial changes in suburban zones. It is particularly harmful because researchers increasingly often speak of urbanised space or functional zones rather than cities because the boundaries between the city and its surroundings grow fuzzy and hard to define with evident spatial characteristics [34,35]. Therefore, researchers [32,33] point out that the traditional division of urban areas into central and suburban is no longer valid. Metropolitan or functional areas do not exist as independent administrative units in Poland, and the boundaries of metropolitan areas in Poland have not been universally defined. Usually, they consist of the core city and a large number of smaller municipalities in the surroundings of the city.

The urban edge is a mix of urban and rural functions and land-use types. Agricultural land on the urban edge is more prone to land abandonment [36], but simultaneously, an increase in suburban population entails growing demand for fresh food products. At the same time, access to food is reduced due to the residential monofunction of suburban areas and large distances to commerce hubs requiring travel by car. For this reason, it seems reasonable to preserve, at least partially, the agricultural function of suburbs and control spatial transformations caused by urban sprawl (such as the increased proportion of discontinuous urban fabric), as a loss of agricultural land to land-use changes such as sprawl may lead to food insecurity [37–39] in functional urban areas (FUA). Urban phenomena, including sprawl, are often discussed separately from rural phenomena [40], disregarding the fact that these are two connected systems. As Cegielska et al. [41] pointed out, the most significant changes in land use and land cover affected agricultural land, with was reduced significantly in Poland in the last decades.

The inadequate definition of urban sprawl [2] renders the results of research on the topic ambiguous. Urban sprawl and suburbanisation can be identified and measured from different perspectives depending on the purpose of the study. Researchers [21,42] point out changes in urban spatial structures in time as the key factor. Galster et al. [42] determined eight dimensions that characterise sprawl: density, continuity, concentration, clustering, centrality, nuclearity, mixed-use types, and proximity. They then proposed a synthetic index for urban sprawl measurement. Similar attributes of sprawl were distinguished by Torrens [43]. Angel et al. [21] further developed Galster's method and presented metrics for the relative measure of sprawl using satellite imagery and population data. Satellite imagery is a common tool for exploring sprawl [44–47], similarly to population data, or in some cases even social-media data [44]. A combination of Corine Land Cover (CLC) and military maps was used to determine how early sprawl was observed in Budapest [48]. Schwarz [49], as well as Arribas et al. [50], used CLC spatial data and Urban Atlas demographic data to characterise the spatial structures of major European cities. CLC was also used to measure sprawl in Polish cities [50].

Polish suburbanisation discourse is dominated by research on its socioeconomic aspect [8,51–55]. Most publications are based on data from public statistical resources (the Local Data Bank of the Polish Central Statistical Office) [1,56,57]. There is not much research on the spatial dimension of urban sprawl in the main metropolitan areas in Poland. Studies on the spatial quality of urban sprawl often are local in scope and focus on determining the number and location of new housing [58] or development density [59,60]. An interesting study of the spatial context of urbanisation was made by Solon [61] in the Warsaw metropolitan area between 1950 and 1990. Solon [61] used several landscape metrics (spatial share, mean patch size, patch size coefficient of variance, mean shape index, mean nearest neighbour distance, mean proximity index, and the interspersion and juxtaposition index) to describe changes in the spatial structure of the landscape. He proved that, in the vicinity of the centre of Warsaw, and in the neighbourhood of the transport routes, built-up areas were characterised by strongly fragmented, irregular shapes. Similar conclusions on changing the peri-urban landscape by transforming the agricultural land into discontinuous urban fabric for suburbs were drawn by Solecka, Sylla, and Świąder [62] for Wrocław. Authors used CLC data, cadastral data, and transactions data to investigate the dynamics of farmland conversion into suburban areas, as well as the actual and predicted state of suburbanisation. More extensive research on the spatial characteristics of urban sprawl in Poland was conducted by Lityński [13] and Cieślak, Biłozor, and Szuniewicz [50]. Lityński [13] used a modified method, which was originally presented by Galster et al. [42]. The proposed method was based on morphological indicators and the land-use mix indicator, and the research area covered the main Polish FUAs. Cieślak, Białozor, and Szuniewicz [50] proposed an overgrowth of urbanisation (OU) index that was based on aggregated CLC data. Their research involved 71 Polish cities with the status of county capitals.

Petrescu [63] applied his original NUASI (normalised Urban Atlas sprawl indicator) in Romania. The metric considers the total urbanised areas and the proportion of discontinuous urban fabric to the total built-up area.

The objective of the present paper was to identify spatial manifestations of suburbanisation in the functional areas of voivodeship capitals in Poland. Poland is divided into 16 provinces known as voivodeships. For the purposes of the study, spatial transformations caused by suburbanisation are defined as land-cover changes. The temporal range of the research is 2006, 2012, and 2018 due to input data accessibility (Urban Atlas data). We employed the NUASI indicator as proposed by Petrescu (2019) to investigate the spatial aspect of suburbanisation. The coefficient reflects the degree of urban sprawl based on the area of discontinuous urban fabric compared to the total urbanised area. In this study, we attempt to answer the question of which Polish cities sprawl the most. The answer will be founded on the assumption that the increase in discontinuous urban fabric is the spatial manifestation of urban sprawl. Therefore, we checked which urban fabric dominated urbanised areas and investigated urban fabric changes in each FUA.

As research gaps and possible contributions of this paper, we have identified: (1) few studies have been conducted on spatial aspects of suburbanisation in the main Polish metropolitan areas, and no study has yet fully discussed the discontinuous urban fabric in these areas and its variability in individual FUAs, and (2) most of the previous studies focused on one case study (3); most research in Poland is based on public statistics, with the spatial-data approach neglected.

2. Materials and Methods

2.1. Study Area

In Poland, dynamic changes in land use and cover related to suburbanisation take place mostly in the suburban zones of large capitals of voivodeships. There are no nationwide documents that would consider the FUA spatial policy as a functional whole. The concept closest to the spatial range of FUA is regions (voivodeships). Still, obligatory spatial development plans for voivodeships are region-specific and do not exceed the administrative boundaries of voivodeships. Meanwhile, FUAs spread and coagulate into functionally coherent units, disregarding administrative boundaries. It means that FUAs are usually only parts of regions and that municipalities that constitute FUAs can be located in various municipalities (such as for Warsaw, Kraków, and Katowice) and may be covered by different spatial development plans. Therefore, there is still room for coordinated urban planning on the voivodeship level. Zooming in on the municipality level, note that every municipality operates within its administrative boundaries, and there is no obligation to coordinate spatial policies with adjacent municipalities that also form the same FUA. Therefore, the number of municipalities comprising a FUA also matters when a joint spatial policy is considered. Therefore, the study involved all 16 capitals of Polish voivodeships with their FUAs (Figure 1). The study area amounts to about 45 thousand km^2. Most FUAs consist of more than ten municipalities; only the FUAs of Zielona Góra and Szczecin have fewer municipalities. The number of municipalities does not necessarily correspond to the area of a FUA, which is evident for Wrocław or Łódź (Table 1).

2.2. Data and Analysis

The work employed a dataset from the Urban Atlas (UA) available on Copernicus [64]. The service is coordinated by the European Environment Agency (EEA), which provides land-cover and land-use information at the European, national, and local levels. The 2006 Urban Atlas covered 319 urban areas in the European Union. Its second iteration in 2012 grew to 800 urban areas, a number retained in the latest 2018 edition. Initially, the UA project identified 21 land-cover and -use categories in 2006, with six more added for 2012 and 2018. The additional categories improve the detail level of the basic ones used in the project's first phase. The changed categories do not affect the NUASI. The study focuses on urbanised areas, while the modified land-cover categories are agricultural, forest, and seminatural areas. The project involved UA data for 2006, 2012, and 2018 for all functional urban areas of the capitals of Polish voivodeships.

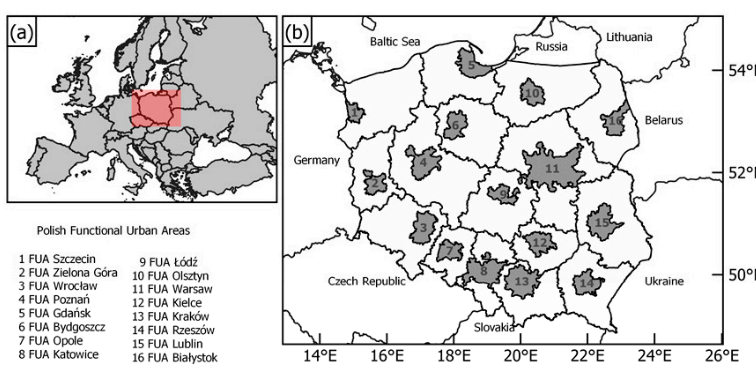

Figure 1. Study area; (**a**) Poland on the map of Europe; (**b**) the investigated Functional Urban Areas in Poland.

Table 1. Investigated FUAs, numbers of municipalities, and area of FUAs.

FUA Name	Number of Municipalities	Area [ha]
Warsaw	90	861,390.09
Katowice	60	394,543.00
Kraków	44	375,796.35
Lublin	33	322,253.81
Rzeszów	28	233,851.62
Poznań	26	309,207.12
Gdańsk	24	263,396.68
Kielce	20	224,323.09
Wrocław	19	264,820.90
Łódź	17	169,527.27
Opole	15	176,558.25
Białystok	13	223,635.64
Bydgoszcz	12	210,024.78
Olsztyn	10	202,358.10
Zielona Góra	9	169,533.28
Szczecin	7	112,898.14

The method of calculating NUASI was proposed by Petrescu [63]. The first step was to reclassify 14 land-cover categories in urbanised areas available in the UA using their urban fabric characteristics and density. Three land-cover and -use groups were created: C1, C2, and C3. The grouping principles are provided in Table 2.

Table 2. Principles for generalising land-cover classes. Source: Petrescu [64].

Urban Atlas Code	Land-Cover Class	Group
11100	Continuous urban fabric	C1
11210	Discontinuous dense urban fabric	C2
11220	Discontinuous medium density urban fabric	
11230	Discontinuous low density urban fabric	
11240	Discontinuous very low density urban fabric	
11300	Isolated structures	
12100	Industrial, commercial, public, military, and private units	C3
12210	Fast transit roads and associated land	
12220	Other roads and associated land	
12230	Railways and associated land	
12300	Port areas	
12400	Airports	
13100	Mineral extraction and dump sites	
13300	Construction sites	

The second step was to aggregate the surfaces of all areas in groups C1, C2, and C3. The computations were performed using the Group Stats plugin for QGIS 3.14 separately for all the years and for all investigated FUAs. The third step involved the calculation of the NUASI [63], that is, a ratio between the area of C2, and the aggregate areas of groups C1, C2, and C3.

$$\text{NUASI} = \frac{\text{area (C2)}}{\text{area (C1)} + \text{area (C2)} + \text{area (C3)}},$$

C1—continuous urban fabric characteristic of cities, very compact building positioning;
C2—discontinuous urban fabric for which suburbanisation can be a reason for growth;
C3—other types of artificial surfaces: any type of areas used by people for purposes other than agriculture, excluding sports facilities, parks, green squares, etc.

Its value indicates the proportion of the investigated area that is covered with the discontinuous urban fabric. The NUASI is always below 1. The results are summarised in tables.

3. Results

The results are presented in tables starting from C1, going through 2006, 2012, and 2018 to C3. The degree of C1 classes coverage reflecting continuous urban fabric for research years are shown in Table 3. The largest such developed area was in the FUA of Warsaw. The proportion of continuous urban fabric in the FUA of Warsaw was 3.66% of its total area in 2006, and it increased to 3.72% in 2018. The FUA with the smallest C1 area was Zielona Góra. Even though it was not the smallest FUA investigated here, its continuous urban fabric area proportion was the lowest: 0.52% in 2006 and 0.49% in 2018 of the total FUA's area.

Table 3. C1 area [ha] in each investigated area in 2006, 2012, and 2018.

				C1		Growth Rate	
FUA	**Area [ha]**	**2006**	**2012**	**2018**	**2012–2006**	**2018–2012**	**2018–2006**
Warsaw	861,390.09	31,554.36	32,004.83	32,044.62	1.43	0.12	1.55
%		3.66	3.71	3.72			
Katowice	394,543.00	7485.93	7558,76	7560.66	0.97	0.03	1.00
%		1.90	1.92	1.92			
Kraków	375,796.35	5138.66	5127.65	5248.31	−0.21	2.35	2.13
%		1.37	1.36	1.40			
Lublin	322,253.81	2682.34	2722.24	2754.51	1.49	1.19	2.69
%		0.83	0.84	0.85			
Rzeszów	233,851.62	1418.65	1434.35	1458.53	1.11	1.69	2.81
%		0.61	0.61	0.62			
Poznań	309,207.12	5097.77	5102.78	5191.53	0.10	1.74	1.84
%		1.65	1.65	1.68			
Gdańsk	263,396.68	5612.64	5696.61	5647.88	1.50	−0.86	0.63
%		2.13	2.16	2.14			
Kielce	224,323.09	1453.37	1226.45	1236.03	−15.61	0.78	−14.95
%		0.65	0.55	0.55			
Wrocław	264,820.90	6243.20	6304.10	6541.92	0.98	3.77	4.78
%		2.36	2.38	2.47			
Łódź	169,527.27	2733.46	2748.18	2754.51	0.54	0.23	0.77
%		1.61	1.62	1.62			
Opole	176,558.25	1026.81	1033.36	1034.78	0.64	0.14	0.78
%		0.58	0.59	0.59			
Białystok	223,635.64	4999.65	5064.62	5182.60	1.30	2.33	3.66
%		2.24	2.26	2.32			
Bydgoszcz	210,024.78	2685.52	2714.36	2746.94	1.07	1.20	2.29
%		1.28	1.29	1.31			
Olsztyn	202,358.10	1430.13	1450.24	1448.36	1.41	−0.13	1.27
%		0.71	0.72	0.72			
Zielona Góra	169,533.28	882.63	834.14	835.84	−5.49	0.20	−5.30
%		0.52	0.49	0.49			
Szczecin	112,898.14	1998.38	2038.79	2047.78	2.02	0.44	2.47
%		1.77	1.81	1.81			

The C1 cover has grown by 2012 in most of the FUAs (Table 3). The increase of C1 between 2006 and 2012 was highest in the FUA of Warsaw, where C1 cover was 31,554 ha in 2006 and grew by 450 ha in six years. The C1 growth rate for 2006–2012 is between 0.1% and 2% in most of the analysed FUAs. However, it decreased in the FUAs of Kielce, Zielona Góra, and Kraków. In Kielce, the reduction was 15.5% or 225 ha; in Zielona Góra it was 5.5%. The FUA of Kraków also lost some C1 area, but merely 0.21%. The largest increase in the proportion of C1 was in the FUA of Warsaw and Szczecin.

Between 2018 and 2012 one of the visible changes took place in Kielce, where the continuous urban fabric area shrank in the past. In 2018, it grew by a mere 0.80%, and the aggregate loss for 12 years was 15%. The FUA of Warsaw also went through a less marked increase: merely 1.4% in 2012 and as little as 0.12% in 2018. The biggest rise was noted in

FUA of Wrocław and FUA of Białystok. In FUA of Białystok, it was relatively stable and amounted to 1.3% in the first period and 2.3% six years later. In the FUA of Wrocław, the change was more significant, from 0.98% in the first period to 3.77% in the second period. As a result, only the FUA of Kielce and the FUA of Zielona Góra experienced a negative change in C1 land cover over the 12 years.

The data for C2 cover (Table 4) show areas where the most dominant cover was discontinuous urban fabric. The FUA of Warsaw had the largest area of C2 cover, but the difference was not as pronounced as in the previous group (Table 3), where the result for FUA of Warsaw was several times higher than in other FUAs. The C2 group covered a much greater area of FUAs than the C1 group. The total C2 area for all FUAs was 246,189 ha, whereas the area of C1 was three times smaller, 82,238 ha. The highest share of C2 in total urban area of 9.77% was observed in the FUA of Rzeszów in 2006. The FUA of Kraków had the second highest share of 9.38% in that year. Both Rzeszów and Kraków had the highest shares of C2 in both 2012 and 2018. The lowest share of C2 in 2006, 2012, and 2018 was in Olsztyn, Zielona Góra, and Białystok (approx. 3%).

Table 4. C2 area [ha] in each investigated area in 2006, 2012, and 2018.

		C2			Growth Rate		
FUA	**Area [ha]**	**2006**	**2012**	**2018**	**2012–2006**	**2018–2012**	**2018–2006**
Warsaw	861,390.09	42,642.41	48,430.37	50,627.06	13.57	4.54	18.72
%		4.95	5.62	5.88			
Katowice	394,543.00	31,795.14	33,786.02	35,302.17	6.26	4.49	11.03
%		8.06	8.56	8.95			
Kraków	375,796.35	35,234.81	38,121.47	40,127.61	8.19	5.26	13.89
%		9.38	10.14	10.68			
Lublin	322,253.81	20,752.50	24,540.03	25,288.12	18.25	3.05	21.86
%		6.44	7.62	7.85			
Rzeszów	233,851.62	22,846.35	24,290.48	25,005.01	6.32	2.94	9.45
%		9.77	10.39	10.69			
Poznań	309,207.12	14,276.26	15,901.54	17,109.61	11.38	7.60	19.85
%		4.62	5.14	5.53			
Gdańsk	263,396.68	12,185.59	14,466.47	166,391.31	18.72	15.02	36.55
%		4.63	5.49	6.32			
Kielce	224,323.09	11,946.32	13,182.47	13,760.25	10.35	4.38	15.18
%		5.33	5.88	6.13			
Wrocław	264,820.90	9761.00	11,190.34	12,185.39	14.64	8.89	24.84
%		3.69	4.23	4.60			
Łódź	169,527.27	14,267.05	15,047.93	16,057.08	5.47	6.71	12.55
%		8.42	8.88	9.47			
Opole	176,558.25	6509.15	7177.61	7263.93	10.27	1.20	11.60
%		3.69	4.07	4.11			
Białystok	223,635.64	5768.20	6454.53	7109.57	11.90	10.15	23.25
%		2.58	2.89	3.18			
Bydgoszcz	210,024.78	6413.44	7473.44	8128.04	16.53	8.76	26.73
%		3.05	3.56	3.87			
Olsztyn	202,358.10	4428.24	4982.56	5427.17	12.52	8.92	22.56
%		2.19	2.46	2.68			
Zielona Góra	169,533.28	3760.58	4372.13	4664.81	16.26	6.69	24.04
%		2.22	2.58	2.75			
Szczecin	112,898.14	3602.70	4224.49	4606.06	17.26	9.03	27.85
%		3.19	3.74	4.08			

In 2012, the C2 cover increased in all the investigated FUAs. The change over the six years was the greatest among all the groups. The most evident expansion of 2281 ha was in the FUA of Gdańsk. The largest growth in all FUAs was for discontinuous very low-density urban fabric. The smallest rise of C2 cover was in the FUA of Łódź, where the growth rate amounted to 5.47%. The mean increase in the growth rate of discontinuous urban fabric in the capitals of voivodeships was 12%. The total area of C2 in all the FUAs was 273 thousand hectares in 2012 (246 thousand in 2006). Between 20012 and 2018 the growth rate was significantly lower, with the exception of the FUA of Łódź, where the growth rate was 6.71% for 2012–2018 and 5.47% for 2006–2012.

The most marked change was noted from 2006 to 2012. The growth was much slower from 2012 to 2018. The growth rate was highest in the FUA of Gdańsk over the twelve years; the accumulated value of the growth rate in Gdańsk was 36.55%.

Details of the C3 cover in 2006, 2012, and 2018 are shown in Table 5. Individual types of artificial surfaces in the FUAs differed significantly. Some of the analysed FUAs did not include fast-transit roads, airports, or access to the sea or other sea routes, so they cannot have ports or associated areas, that form C3 group. The FUAs of Lublin, Bialystok, Zielona Góra, and Szczecin did not have airports or group 12,400 areas. Similarly, ports, category 12,300, can only be found in the FUA for Szczecin, Gdańsk, Wrocław, and Warsaw. The largest C3 area was found in the largest investigated FUA, as was the case earlier. In relative terms, the largest such developed area was the FUA of Katowice. The functional urban area of Katowice is one of the most urbanised areas because of industrial zones, mineral extraction sites, and factories.

Table 5. C3 area [ha] in each investigated area in 2006, 2012, and 2018.

			C3			Growth Rates	
FUA	**Area [ha]**	**2006**	**2012**	**2018**	**2012–2006**	**2018–2012**	**2018–2006**
Warsaw	861,390.09	37,461.85	40,804.55	42,547.39	8.92	4.27	13.58
%		4.35	4.74	4.94			
Katowice	394,543.00	34,716.85	36,271.69	37,615.46	4.48	3.70	8.35
%		8.80	9.19	9.53			
Kraków	375,796.35	17,147.86	18,300.40	19.011.87	6.74	3.87	10.87
%		4,56	4,87	5,06			
Lublin	322,253.81	8696.71	10,631.47	10,796.28	22.25	1.55	24.14
%		2.70	3.30	3.35			
Rzeszów	233,851.62	6488.28	7735.46	7700.47	19.22	−0.45	18.68
%		2.77	3.31	3.29			
Poznań	309,207.12	15,714.85	17,352.80	20,095.13	10.42	15.80	27.87
%		5.08	5.61	6.50			
Gdańsk	263,396.68	15,158.32	16,567.59	17,144.67	9.30	3.48	13.10
%		5.75	6.29	6.51			
Kielce	224,323.09	7271.92	8531.43	9002.57	17.32	5.52	23.80
%		3.24	3.80	4.01			
Wrocław	264,820.90	13,340.03	14,353.67	15,026.10	7.60	4.68	12.64
%		5.04	5.42	5.67			
Łódź	169,527.27	11,333.22	11,956.47	12,782.06	5.50	6.90	12.78
%		6.69	7.05	7.54			
Opole	176,558.25	5580.94	5836.90	6219.20	4.59	6.55	11.44
%		3.16	3.31	3.52			
Białystok	223,635.64	6911.20	7707.43	8555.84	11.52	11.01	23.80
%		3.09	3.45	3.83			
Bydgoszcz	210,024.78	8055.47	8490.64	9642.28	5.40	13.56	19.70
%		3.84	4.04	4.59			
Olsztyn	202,358.10	5132.24	4957.59	6108.44	−3.40	23.21	19.02
%		2.54	2.45	3.02			
Zielona Góra	169,533.28	4685.97	5056.16	5172.52	7.90	2.30	10.38
%		2.76	2.98	3.05			
Szczecin	112,898.14	6642.79	7140.21	7339.50	7.49	2.79	10.49
%		5.88	6.32	6.50			

Over the six-year period between 2006 and 2012, only one area stands out among all the expanding FUAs, Olsztyn. Its built-up area decreased by 3.4%, which is opposite to the other FUAs. The reason for such a small change was the reduction in mineral extraction sites by 240 ha, similar to construction sites, which shrunk by about 90 ha in six years. Land-cover classes under C3 grew in all of the investigated FUAs in 2018 with the exception of the FUA of Rzeszów, where the area shrunk by 0.5% or 35 ha from 2012. The functional urban area of Rzeszów grew in terms of all land-cover categories except for the last one, that is, construction sites. This category grew smaller by 880 ha in six years.

We calculated the NUASI for each year (2006, 2012, and 2018) and for all functional areas of the capitals of Polish voivodeships from UA land-use and -cover data (Table 6). The proportion of discontinuous urban fabric grew in most analysed FUAs. It varied from 0.47% (the FUAs of Łódź and FUA of Kraków) to 4.86% (the FUA of Gdańsk).

Table 6. NUASI [%] for 2006, 2012, and 2018 and changes from 2006 to 2018 for all FUAs.

	Warsaw	**Katowice**	**Kraków**	**Lublin**	**Poznań**	**Wrocław**
NUASI 2006	38.19	42.97	50.35	64.59	40.69	33.26
NUASI 2012	39.95	43.53	50.58	64.76	41.46	35.14
NUASI 2018	40.43	43.87	50.82	65.17	41.69	36.10
change 2018–2006	2.24	0.90	0.47	0.59	1.00	2.84
	Rzeszów	Białystok	Bydgoszcz	Olsztyn	Opole	Zielona Góra
NUASI 2006	74.29	32.63	37.39	40.29	49.62	40.57
NUASI 2012	72.59	33.57	40.01	43.74	51.09	42.60
NUASI 2018	73.19	34.10	39.62	41.80	50.03	43.71
change 2018–2006	−1.10	1.47	2.23	1.51	0.41	3.14
	Gdańsk	Kielce	Łódź	Szczecin		
NUASI 2006	36.97	57.79	50.35	29.42		
NUASI 2012	39.39	57.46	50.58	31.52		
NUASI 2018	41.83	57.34	50.82	32.92		
change 2018–2006	4.86	−0.45	0.47	3.49		

The analysis of C2 cover and NUASI changes in the FUAs of Rzeszów and Kielce demonstrated that discontinuous urban fabric did not always grow. In the FUA of Kielce, the value of the NUASI decreases by about 0.20% in six years on average. The change was not due to the slower dispersion of developments, which grew by 1813 ha in 12 years. One of its causes was new C3 areas that grew by 23.8% from 2006 to 2018 (1730 ha). Therefore, the proportion of discontinuous urban fabric to all the groups dwindled.

The NUASI for the FUA of Rzeszów dropped 1.1% over 12 years. Discontinuous urban fabric on FUA of Rzeszów amounted to 73% of the entire urbanised area (sum of C1, C2, C3). Data for the first period show that Rzeszów's fabric was significantly discontinuous already in 2006. Over the twelve analysed years, the proportion of discontinuous urban fabric declined, making room for other urbanised land-cover types. Therefore, the discontinuous urban fabric did not grow from 2006 to 2018, as did the other categories. The decrease in the NUASI in the FUAs of Rzeszów and Kielce was caused by the increase in the area of C3.

All the analysed FUAs were covered in discontinuous urban fabric. The proportion of discontinuous urban fabric (C2) in the urbanised areas of individual FUAs is shown in choropleth maps (Figure 2). The greatest share of C2 cover in the total urbanised area in all the years was found in southeastern Poland with the FUAs of Rzeszów, Lublin, Kielce, and Kraków. The FUA of Rzeszów has the largest share of discontinuous urban fabric from among the investigated FUAs. The values of the NUASI for the FUA of Rzeszów exceeded 72% in every year. It was followed by the FUA of Lublin (above 64% in each year), the FUA of Kielce (over 57% in each year), and the FUA of Kraków (over 50% in each year). The situation in northwestern Poland was the opposite. In the last investigated year, the FUA of Szczecin was covered with 1.8% continuous urban fabric (C1). Discontinuous urban fabric was 4%, and the C3 group covered 6.5%. In terms of proportions in urbanised area, C1 covered 15%; C2 was 33%, and C3 was 52%. Szczecin is the only functional urban area with the share of discontinuous urban fabric in urban areas below 33%. Most of the cities range from 40 to 50%, including the largest FUA, Warsaw.

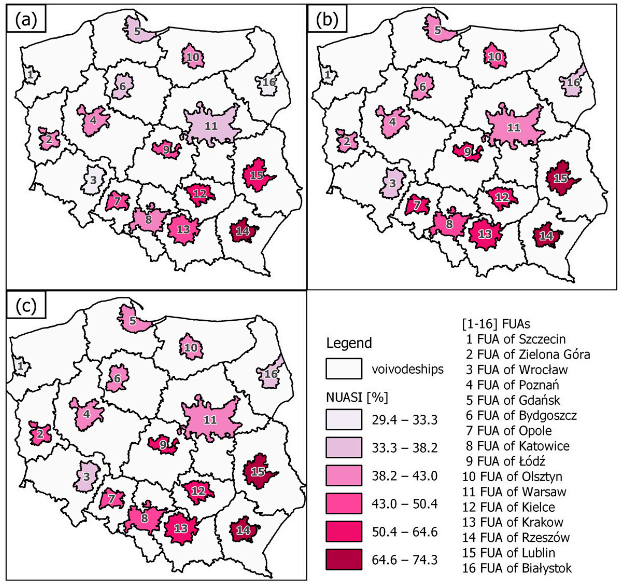

Figure 2. The NUASI in 2006 (**a**), 2012 (**b**), and 2018 (**c**).

We proved that urban fabric grew the fastest from 2006 to 2012, which is demonstrated by NUASI changes (Figure 3). In most of the studied areas, the second period from 2012 to 2018 was a time of slower inflation of discontinuous urban fabric, which is demonstrated by a nearly two-time-lower value of the NUASI indicator. The described tendency is especially present in the FUA of Olsztyn, where NUASI change between 2018 and 2012 was −1.94%, but between 2012 and 2006, it was 3.45%.

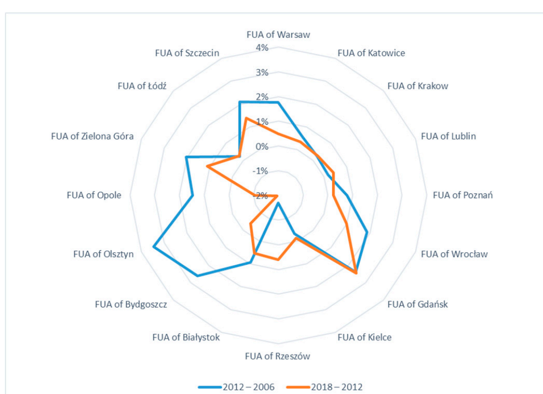

Figure 3. The NUASI changes between 2018 and 2012, as well as 2012 and 2006.

All urban sprawl types proposed by Harvey and Clark [31] are present in Polish FUAs, i.e., low-density sprawl and ribbon development, as well as leapfrog development. As noticed by Sýkora and Stanilov [65], there are two main models of the spatial development of suburbia in post-socialist countries. In the first one, suburban buildings are concentrated in a relatively limited number of nodes of varying volumes in which housing, workplaces, and services are mixed. These nodes of suburban development are usually anchored in the historical structure of the village. The second pattern of suburban development takes the form of scattered development, with a large number of clusters, many of which are monofunctional (mostly residential). We combined the spatial distribution of built-up areas (C1 + C2 + C3), boundaries of urban core, and main roads to show the types of urban sprawl present in Poland. Although all types of urban sprawl are present in all Polish FUAs, there are regional features that are worth highlighting. The least-concentrated areas are located in the southern part of Poland (Figure 4a–c). Especially in the FUA of Krakow and the FUA of Rzeszów, there are examples of scattered development. In the FUA of Rzeszów, as well as the FUA of Kielce, the development of new buildings, mainly residential ones, is located on a continuous row along the main road (Figure 4b,c). A trend of edge development is strongly visible in central Poland (Figure 4d,e). In the FUA of Wrocław, there are many examples of leapfrog development. In northern Poland, the dispersion of buildings is not as advanced as in southern Poland. The development of new buildings is based on previously existing villages (Figure 4g,h).

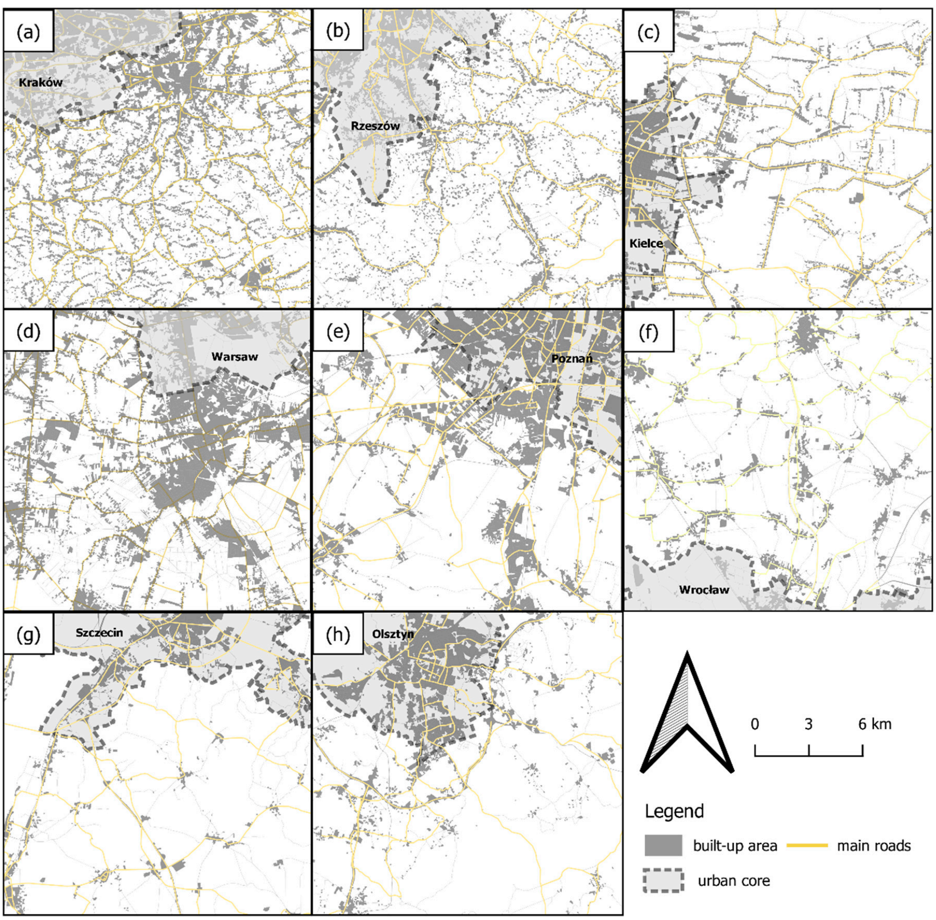

Figure 4. Examples of regional variation of urban sprawl forms: (**a**) scattered development in the FUA of Krakow (**a**) and in the FUA of Rzeszów (**b**), ribbon development in the FUA of Kielce (**c**), edge expansion in the FUA of Warsaw (**d**) and in the FUA of Poznań (**e**), leap frog development in the FUA of Wrocław (**f**), development based on previously existing villages in the FUA of Szczecin (**g**) and in the FUA of Olszyn (**h**).

4. Discussion

The primary assumption in this paper was that the spatial manifestation of urban sprawl was an increase in the proportion of discontinuous urban fabric to the total urbanised area [26,66] reflected in the NUASI. The NUASI takes into account the entire urbanised area, but it also considers its ratio to the area of the discontinuous urban fabric. This study helps determine which urban fabric expands the most. The present study demonstrated that the fastest-growing type of urban fabric was discontinuous urban fabric, which was the dominant type of urban fabric in all the years in the FUAs of Rzeszów, Lublin, Kielce, Kraków, and Łódź. Therefore, urban sprawl takes place in all of the functional areas of the capitals of Polish voivodeships. Still, a difference between northern and southern Poland was identified. The highest values of the NUASI for the years of interest were found in the FUAs in southern and southeastern Poland. Polish agricultural holdings are among the smallest in Europe [67]. The parcels are small, and their shapes are often problematic [68]. The issue is evident in the agricultural land of southern Poland, where fragmentation is the worst [69]. Therefore, it seems justified to claim that the significant proportion of discontinuous urban fabric in urbanised areas of southern Poland is aggravated by historical fragmentation of agricultural holdings, significantly elongated (band-like) parcels [68], and an insufficient land consolidation effort. Such an unfavourable and dysfunctional development of urbanised areas could be aided by sound spatial planning. Many authors emphasised the inefficiency of the spatial planning system in Poland and the failure to implement regulations [70–75]. Too often the development of urbanised areas depends on individual administrative decisions instead of comprehensive spatial development plans. All of this results in a positive-feedback situation. Fragmentation and small sizes of farms, as well as small sizes of agricultural parcels, make it easier to sell land and convert it into non-agricultural and non-forest use, which fosters urban sprawl. On the other hand, urban sprawl may reinforce the existent adverse spatial structure by developing small parcels instead of their consolidation, planning of infrastructure, and division for sale [68].

As Nuissl and Rink [76] highlighted, suburbanisation in post-socialist countries differed from suburbanisation in Western Europe. While in Western Europe, suburbanisation took place in an environment of strong population and economic growth, in post-socialist countries, there was stagnation in population and economic transformation. Kajdanek [77] claimed that the most important difference between suburbanisation in Poland and in Western Europe was the scale and the size of suburban area. In Poland, suburban areas developed a short distance from the central city and were not that extensive. Similar conclusions were reached by Solon [61] in his research on the suburban area of Warsaw. Solon [61] noticed that the strong influence of the city ends at a distance of 4–6 km from the centre and transportation routes. Polish researchers [78,79] agree that Polish suburban areas are characterised by chaotic development and the irrationality of spatial systems, as well as the high consumption of space due to the large dispersion of buildings [11]. Urban sprawl in Poland displays similar features to those observed by Repaská, Vilinová, and Šolcová [80] in the suburbs of Nitra. These features are: small residential plots, dense built-up areas, cul-de-sacs, and private roads.

It is difficult to compare the results of various studies due to the diversity of methods and input data. Cieślak et al. [50] investigated urban sprawl in the capitals of Polish districts using aggregate urbanised areas based on CLC data. In our opinion, the highly fragmented suburban development reduces the usefulness of CLC data for research on urban sprawl in Poland. The legitimacy of the use of CLC data in the urban sprawl measurement is also questioned by Solecka et al. [62], who proved that almost half of housing plots are located outside of the area classified as discontinuous urban fabric by CLC in the research of the suburban area of Wroclaw. Moreover we believe the use of aggregate urbanised areas delineated with arbitrary aggregation parameters have the potential of excluding areas with discontinuous urban fabric (leapfrog development) from studies on urban sprawl. Therefore, we selected all urbanised areas for the present study, with a particular focus on the discontinuous urban fabric. Other studies [53,60] analysed only the area of one city or one FUA, as usually the data used for such research are high-resolution data, and the studies are usually very detailed. We could analyse all the largest Polish cities simultaneously thanks to the use of Urban Atlas data.

The selection of input data determines the selection of the study area. We employed Urban Atlas data in our research as they are more accurate than CLC data. The advantage of CLC data over Urban Atlas data is that they cover all of Poland, which makes them adequate for analysing any study area. Thus, the first limitation of our method is the scope of the data. The research is possible only for FUAs but not for the entire country. The second limitation is the inability to measure NUASI for other time periods than those related to Urban Atlas data. However, the use of national survey datasets for the calculation of NUASI may be considered for the further research.

The issue of the study area is linked to the problem of precise delimitation (the determination or assumption of boundaries of the area affected by urban sprawl). Lityński [13] delineated areas under urban sprawl using a set of variables in accordance with the literature, excluding polycentric agglomerations for simplicity's sake. Cieślak [50] selected district cities and municipalities adjacent to them as areas potentially affected by urban sprawl. In the present study, we selected all of the FUAs of the capitals of Polish voivodeships. This way, the results can be compared across the country and to other European countries. The comparison should involve cities that are regional capitals. Note that the policy for identifying FUAs with population density and travel-to-work flows is consistent with the principles for identifying areas potentially under urban sprawl.

We demonstrated that urban fabric grew the fastest from 2006 to 2012, which is consistent with results by Cieślak et al. [50]. Still, the present study demonstrates that discontinuous urban fabric expanded the most rapidly among all urban fabric types. The period from 2012 to 2018 was a time of slower inflation of discontinuous urban fabric. It still grew in relation to the total developed land, but the increase was nearly two times smaller than from 2006 to 2012. Cieślak at al. [50] also noticed the slower expansion of urban fabric in general from 2012 to 2018.

According to Small [81], the public and policymakers compare urban sprawl to a sickness that is embodied in harmful signs but cannot be fully comprehended and prevented and the root causes of which remain unknown. In addition, the literature shows that urban expansion is quicker than urban population growth [82]. It is also visible in Polish local development plans, in which extensive areas are designated as built-up areas [70,83]. Sprawl should be viewed from the broader perspective of agricultural land loss, as new developments often invade space designated for agricultural use. It can disrupt food security [84,85] and cause problems with food availability [86]. Therefore, function mix is important in spatial planning so that residents have access to services and food. Growing food close to the city improves the health of its inhabitants and opens the possibility of creating direct channels that may increase profitability [87]. Therefore, urban agriculture could be a remedy for food insecurity and facilitate the development of resilient and empowered communities, improvement of health, and the reuse of abandoned properties [88]. The reduction of the necessity to use cars to satisfy basic needs can also help with the obesity epidemics [89].

The primary result of the present study is the NUASI values, which indicate the proportion of discontinuous urban fabric for each FUA. The NUASI was calculated for the entire FUAs here. However, thanks to the design of the indicator and the nature of the Urban Atlas input data, it is possible to calculate the NUASI for the city core, suburban zone, and individual municipalities within FUAs. It could be the next research step.

Values of the NUASI could help devise national and regional spatial policies. Moreover, NUASI for individual municipalities could help define local spatial policies. Urban Atlas data are provided every six years. One can verify whether implemented spatial policies to limit urban sprawl work by calculating the indicator regularly. Should the NUASI for the latest data be high, the effort would be fruitless.

Some studies show that the increase in population is not as dynamic as the increase in urbanised areas [50,70,82,83]. Therefore, it would be reasonable to regularly compare the pace of changes in the proportion of discontinuous urban fabric in total urbanised areas with demographic processes in the investigated space. Such monitoring is advisable on the national and regional levels (based on changes in the NUASI in individual FUAs) and on the local level (NUASI for individual municipalities).

5. Conclusions

Suburbanisation is highly dynamic. Areas around cities witness violent spatial transformations. The changes vary in nature and intensity depending on local conditions. The spatial dimension of suburbanisation is increasingly apparent, not only in the United States or Western Europe but also in Poland. It is embodied mostly in land-cover and land-use change involving an increase in the proportion of urbanised areas and discontinuous urban fabric in the total area of developed land. The spatial analysis was aimed at finding differences in land-cover ratios by individual urbanised land categories. It was based on open-access Urban Atlas data. The employed method was the NUASI. The study involved 16 capitals of voivodeships in Poland with their commute zones, referred to as functional urban areas.

A series of calculations confirmed the urban sprawl tendency identified in the literature. Additionally, the values of the NUASI reflected the course and pace of changes in individual urban land-cover types. The results show that discontinuous urban fabric underwent the largest increase in developed land from 2006 to 2018. Discontinuous urban fabric expanded the most from among all of the analysed land cover groups, particularly in the first investigated period from 2006 to 2012. The value of the NUASI for each city was high and varied from 31% to 74%. The summary of the values for the FUAs of Kielce and Rzeszów indicates that discontinuous urban fabric can relatively shrink. However, it is not due to the cessation of development scattering. The primary cause of this change is the occurrence of new areas with an artificial surface and compaction of the existing discontinuous urban fabric. The study shows that urban sprawl is the most intense in southern and southeastern Poland.

An excessive proportion of discontinuous urban fabric in the entire developed area has no benefits. It mainly generates costs of management or transport and contributes to the loss of open areas for potential agricultural production. It is necessary to improve spatial planning so that individual land-cover groups grow in accordance with planned targets with the proper functional mix to prevent adverse repercussions of urban sprawl. It is important that the C1 and C3 land-cover groups be relatively greater. The extensive continuous urban fabric and such land-cover types as transit roads, airports, or railways are characteristic of developed cities. The high share of C1 land can also demonstrate the effective implementation of compact city principles, which has often been discussed as the antithesis of urban sprawl or decentralisation.

The NUASI can easily indicate changes in urban sprawl. It has no inherent restrictions. The indicators can be applied to a single FUA in a selected year or a series of measurements to build comprehensive summaries to reflect the sprawl of discontinuous urban fabric over the years. Furthermore, the indicator can be applied to any European city identified as a functional urban area in the Urban Atlas.

Our results can be useful for policymakers and decision-makers to show the complexity of dynamic changes in the urban fabric. Such knowledge is necessary to develop tailored spatial planning documents that could prevent the excessive loss of agricultural land and show where sprawl is the most advanced.

Author Contributions: Conceptualization, R.-C.R., C.B. and S.A.; Formal analysis, R.-C.R. and S.A.; Methodology, R.-C.R. and S.A.; Visualization, R.-C.R.; Writing—original draft, R.-C.R. and C.B.; Writing—review & editing, R.-C.R. and C.B. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Science Centre, Poland, under project no. 2016/21/D/HS4/00264 and by the project "Cultural heritage of small homelands" no. PPI/APM/2018/1/00010/U/01, financed by the Polish National Agency for Academic Exchange as a part of the International Academic Partnerships.

Data Availability Statement: Publicly available datasets were analyzed in this study. This data can be requested here available online: https://land.copernicus.eu/local/urban-atlas (accessed on 19 October 2021).

Conflicts of Interest: The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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Article

Transforming the Use of Agricultural Premises under Urbanization Pressures: A Story from a Second-Tier Post-Socialist City

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Abstract: Diverse aspects of de-agrarianization, which is manifested by the cessation or significant reduction in agricultural activities, have been clearly visible at the outskirts of large cities in Central Europe in recent decades. The key drivers behind this process include increased pressures to cover peri-urban agricultural land by new developments, inadequate protection of agricultural land, ineffective implementation of urban planning policies, low recognition of the importance of agriculture, and overall changes in people's dietary habits. Urbanization pressures undoubtedly belong to the factors intensifying overall de-agrarianization, as urban farmers are usually not able to compete with other urban functions. This article focuses on more in-depth understanding of the driving forces behind de-agrarianization processes that are specific to post-socialist cities. As a case study, Brno, a second-tier city in the Czech Republic, was selected. In the first part, the conceptual framework and drivers of de-agrarianization are discussed specifically for the case of large Central European post-socialist cities. In the next part, we explore by means of a set of qualitative interviews the case study of the regeneration of the area of a former Cistercian monastery in Brno that was traditionally used for agricultural purposes, but recently was redeveloped for a university campus. Our findings signal procedural issues connected to the preservation of architectural heritage during the regeneration that frequently end up with only fragments being preserved. We also demonstrate a decline in the use of urban agricultural properties that are hastily transformed into a new urban environment under extremely strong urbanization pressures. We argue that even in economically prosperous cities with highly neoliberal competition between possible urban land uses, agriculture must be considered a relevant and highly important urban function and more protected by planning tools.

Keywords: de-agrarianisation; post-agricultural brownfield; regeneration; urban renewal; Central Europe; urbanization; post-socialist city

Citation: Klusáček, P.; Martinát, S.; Charvátová, K.; Navrátil, J. Transforming the Use of Agricultural Premises under Urbanization Pressures: A Story from a Second-Tier Post-Socialist City. *Land* **2022**, *11*, 866. https://doi.org/10.3390/land11060866

Academic Editors: Carmen Delgado Viñas and María L. Gómez-Moreno

Received: 30 April 2022
Accepted: 7 June 2022
Published: 8 June 2022

1. Introduction

The utilization of land in contemporary neoliberal cities is fundamentally driven by market relations [1], which tend to crowd out and displace functions that bring lower rent [2]. This is especially true in post-socialist cities [3], where competition for land was highly deformed for the majority of the second half of the 20th century during the era of socialism [4]. On the contrary, the post-socialist era after 1990 has rapidly brought even more extreme market-related pressures searching for new spaces for new uses and re-uses of urban land [5]. The governance of post-socialist cities is slowly adapting to new challenges to which that it has not yet been exposed [6,7].

1.1. Factors Affecting Urban Agriculture in Central European Cities

Among the urban functions that found themselves in highly precarious and hardly competitive positions in the new era after the 1990s is agriculture [8]. Over the course of the last three decades, urban and peri-urban agriculture has begun to rapidly disappear from post-socialist cities, being replaced by more economically profitable activities, regardless of the benefits and social and environmental potential that agriculture represents for urban dwellers [9]. Undoubtedly, the main drivers of de-agrarianization in Central European cities, which is manifested by the cessation or significant reduction in agricultural activities [10], include, for example: (i) emerging large-scale urbanization pressures to cover peri-urban land with new developments, (ii) the import of agricultural products from countries (regions) where they can be produced at cheaper prices and thus render local producers unable to compete [11], (iii) a change in the dietary habits of the population [12] (e.g., a decline in the popularity of dairy products), (iv) prioritization of more profitable urban land uses by owners [13], (v) inadequate urban planning policies [14], (vi) reduced attractiveness of the agricultural sector for new entrants [15], and (vii) low acknowledgement of the importance of urban agriculture [16]. All these driving forces have contributed to a drastic reduction in agricultural activities in urban areas in the last three decades.

On the other hand, the growing attractiveness of small-scale and rather lifestyle oriented urban agriculture among urban dwellers can be clearly observed [17]. Diverse forms of urban agriculture are emerging from the roots of local food initiatives. Numerous types and varieties of allotment gardening that survived the pressures of the urban post-socialist transition are thriving [18]. The social, cultural, and environmental benefits of urban agriculture for urbanites are confirmed by numerous studies (e.g., [19,20]).

General urbanization (and especially suburbanization) pressures are undoubtedly one of the underlying factors [21] that amplify overall urban de-agrarianization from a spatial perspective [22,23] as agricultural activities are usually unable to compete with expanding urban functions [24]. Contrarily, de-agrarianization does not seem to be solely concentrated in urban space or immediately proximal to it but is also detectable in areas with a poor quality of land and distant rural locations. In this case, it would be more appropriate to use the term de-intensification [25] as some kind of land management is still possible and the change in the usage of land is not irreversible [26]. The paths towards both aforementioned processes are mutually interlinked, although the motivations of land managers in cities and rural peripheries differ [27].

1.2. Urban Agricultural and Territorial Delimitation of Cities

The on-site situation and intensity of urban agriculture is certainly site-specific; however, it seems to be heavily influenced by a territorial delimitation of the city's administrative boundaries [28]. Here is where urban planning policies towards urban agriculture become enormously important [29] and can play a leading role in promoting the agricultural use of land in cities [30]. While some cities have outgrown their administrative boundaries by the size of their built-up area, in other cities the administrative boundaries have been defined in a more generous way [31], so that rural areas and the presence of undeveloped land in the form of agricultural or forest land have been placed under the local self-government of the city. This discrepancy between administrative boundaries and functional regions has been discussed in more detail by [32]. In the post-socialist environment, it is usually the case that towns have been defined more broadly [33,34]. The rationale for this phenomenon can be found in the era of a centrally controlled economy, where food self-sufficiency was among the key national strategies and thus was projected by the emergence of urban (or peri-urban) agriculture on the local level [18]. We can build on this tradition when supporting local food systems. The link towards sustainability seems to be clear as local agricultural production supplying urban dwellers with a supply of fresh food is inevitable for building healthier and more sustainable life in cities [35,36].

1.3. Brownfield Regeneration in Brno

We need to shift our attention now to better comprehend the context of our case study located in Brno, which is the second most populated city in the Czech Republic (population 379.5 thousand in 2022). In the period after 1989, when the post-socialist era started, agriculture in Brno underwent turbulent and complex transformation processes. These can be clearly manifested in a dramatic change in the scope and scale of local urban agricultural production. More specifically, for example, a traditional greenhouse-type of urban agriculture quickly disappeared due a lack of competitiveness with cheaper food imports and found itself largely abandoned. Additionally, large urban developments were built on soils of high quality, which were irreversibly lost. More than 800 hectares of agricultural land, i.e., circa 3% of the city area, has lost its agricultural function in the last three decades. Another important factor that has contributed to such a shift is changing legal relations concerning land use [37]. Large-scale agricultural cooperatives that were created in the socialist era disappeared in most cases and were replaced by other types of business-driven entities by means of privatizations and restitutions of agricultural properties [38]. In short, both residential and commercial suburbanization and consequent urban sprawl had an immense impact on the scale of the loss of agricultural land and urban expansion at the expense of open landscape [39,40]. These processes naturally led to the change in function of numerous urban and peri-urban agricultural properties and the creation of abandoned agricultural brownfields [41,42]. Unfortunately, after the reintroduction of the market economy in the Brno urban environment, only minor agricultural activities were preserved and economically strong enough to be able to compete with more profitable urban functions. Brno inherited rather wide urban administrative boundaries from the socialist period compared to, for example, cities in neighboring Austria [43]. Therefore, the contrast between agricultural landscape and urban landscape within Brno's city borders is still visible (Figure 1) and must be carefully maintained. Statistical data show that the decline of agricultural and arable land in Brno developed new dynamics under the conditions of the market economy since 1992, in the era of the Czech Republic (please see Table 1).

Figure 1. Contrast of agricultural landscape and urban landscape in Brno—city horses in a pasture near Panská Lícha in Brno—Obřany (Photo: P. Klusáček).

Table 1. Land use changes in Brno between 1992 and 2019 (absolute numbers are in hectares).

	1992		2019		Change 2019/1992
	abs.	**%**	**abs.**	**%**	**%**
Arable land	5706	24.79	5010	21.76	−12.20
Vineyards	36	0.16	17	0.07	−52.19
Gardens	2105	9.14	2061	8.95	−2.09
Fruit orchards	260	1.13	221	0.96	−15.08
Permanent grassland	318	1.38	326	1.41	2.39
Agricultural land—total	8425	36.60	7634	33.16	−9.39
Forest land	6376	27.70	6396	27.78	0.31
Water land	447	1.94	452	1.96	1.08
Built-up area	2095	9.10	2111	9.17	0.77
Other land	5677	24.66	6427	27.92	13.22
Non-agriculturalland—total	14,595	63.40	15,386	66.84	5.42
Area—total	23,020	100.00	23,020	100.00	0.00

Data—Czech Statistical Office.

The municipality of Brno, which is the administrative center of the South Moravian Region, is actively supporting brownfield regeneration in order to reduce its occurrence. As post-agricultural brownfields can be frequently found among the abandoned sites, special effort is devoted to enabling their new use. For example, the Brno city administration together with the Regional Development Agency of South Moravia have created specialized databases of non-regenerated brownfields, published successfully regenerated brownfields, and organized workshops for stakeholders, and are much more successful in this area compared to other regional cities and regions of the Czech Republic [6]. These databases were used for development and testing of the TIMBRE brownfield prioritization tool [44,45]. Quantitative surveys of available data [46,47] have shown that brownfields can usually successfully compete with greenfields, especially in core residential areas and in locations well connected to major transport networks. The research focused on examples of good practice in successfully regenerated brownfields in Brno [4,48] and other places in the South Moravian Region (Czech Republic) [23,49] showed that in terms of specific case sites networking is important.

This article focuses on enabling an advanced understanding of the brownfield regeneration process as an expression of a long-term de-agrarianization. As a case study, Brno, a second-tier post-socialist city in the Czech Republic, was selected. We employed qualitative research methods to better understand the particularities of the regeneration of a former Cistercian monastery where agricultural activities were traditionally undertaken, but as a result of the regeneration, a new complex serving the development of higher university education (an university campus) was developed.

The main objective of the paper is to identify and interpret the main driving forces that influence long-term de-agrarianization in the urban environment in the post-socialist context.

2. Materials and Methods

2.1. Case Study Area

Previous brownfield research in Brno primarily focused on the particularities of the spatial patterns of urban brownfield regeneration. It was discovered that post-agricultural brownfields tend to be located at the urban periphery, where facilities of peri-urban agriculture had been widely developed during the socialist era [50]. In this research, we deal with long-term de-agrarianization in Brno. We focused on the case study area of a former monastery, estate, and brewery in Brno (Královo Pole city district), which gradually lost its agricultural function during the second half of 20th century and was regenerated for an university campus [51] (pp. 31–33). The selection of the case study area was based on a wider and controversial public debate about which parts of the heritage (architectural, spiritual, agricultural) should be preserved in order to maintain the genius loci of the site. To introduce the context, the vast majority of post-agricultural brownfields in Brno were sites that had been built during the socialist era to serve the needs of intensive suburban agriculture whose architectural value was minimal. These sites, frequently constructed for a provisional use with poor quality constructions, were usually demolished after 1990 and were followed by completely newly built developments. These examples include the sites with glasshouses (e.g., [52], pp. 22–24 or pp. 37–39) or premises of former agricultural cooperatives. In the context of post-agricultural brownfields in Brno, our case study is unique and deserves a more in-depth look.

In 1953, our case study area (former monastery) was still located on the northern edge of the built-up area of Brno with abundant agricultural land in its immediate vicinity (Figure 2). In the following decades, however, intensive urbanization prevailed, leading to extensive changes in the surrounding agricultural land for urban development (please see Figure 3, which illustrates how the neighborhood changed). The case study area consists of two units: (i) the western part, which had an economic use focused primarily on the storage and processing of agricultural products, while (ii) the eastern part was historically used as a monastery (Figures 4 and 5). During the regeneration of the site, which occurred in the period 2004–2014, the eastern part with the historic monastery was mostly rebuilt, while the western part was largely demolished and only remnants of agricultural architecture remained. In particular, a former malt house (Figure 6) was preserved and was incorporated into the regeneration project (Figure 7). Both campuses were interconnected by a bridge during the regeneration (Figure 8). Selected basic characteristics of the regeneration project are listed in Table 2 for better and systematic overview.

Figure 2. Location of the case study area within the settlement system of Brno in 1953; source: https://ags.cuzk.cz/archiv/?start=lms (accessed on 15 May 2022).

Figure 3. Location of the case study area within the settlement system of Brno in 2020; source: https://ags.cuzk.cz/archiv/?start=lms (accessed on 15 May 2022).

Figure 4. Western and eastern parts of the case study area in aerial photograph before the regeneration in 2003; source: https://ags.cuzk.cz/archiv/?start=lms (accessed on 15 May 2022).

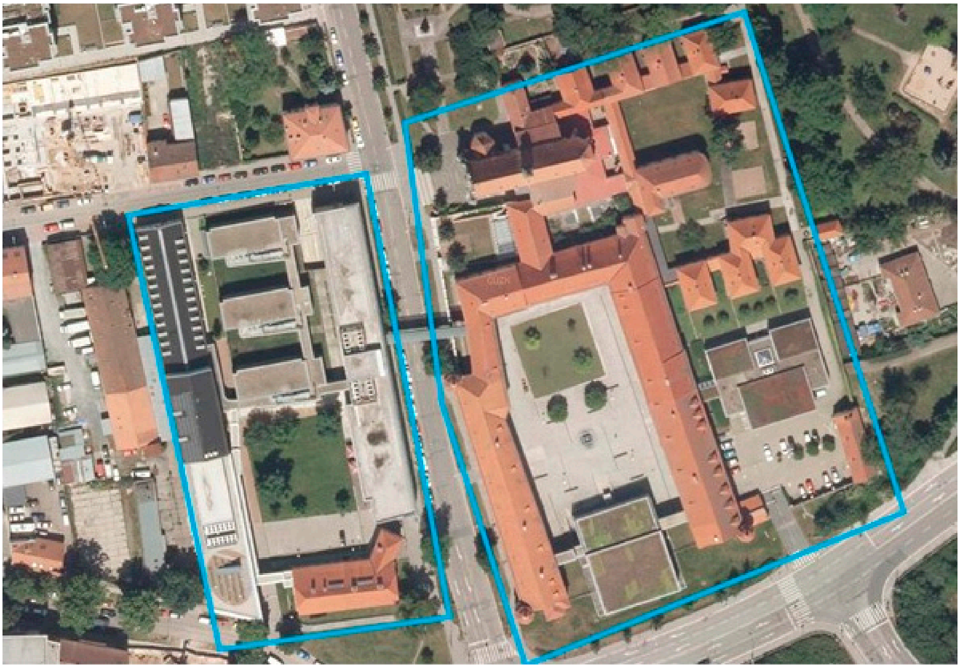

Figure 5. Detail of the case study area in aerial photograph after the regeneration in 2020; source: https://ags.cuzk.cz/archiv/?start=lms (accessed on 15 May 2022).

Figure 6. View of the courtyard facade of the former malt house; source: [53].

Figure 7. Rebuilt former malt house incorporated into new modern architecture to meet the needs of the Faculty of Information Technologies, University of Technology (Photo: K. Charvátová).

Figure 8. Bridge connection of the western part of the site with the eastern historical part with contrasting architectural styles (Photo: K. Charvátová).

However, let us turn back to the past. The case study site has been used for agricultural purposes since the 14th century. From a long-term historical perspective, it can be stated that the regeneration project is not the first redevelopment of the site that has brought about a significant land-use change here (please details in Figure 9).

Table 2. The selected basic characteristics of the regeneration project in Brno-Královo Pole.

Characteristic	Description
Total area of site	3 hectares
Investments in the redevelopment of site	32 million Euro
Type of financing	Public
Approximate number of students using the site after regeneration annually	2500
Start and completion of the regeneration project	2004–2014

Source: Authors' own processing.

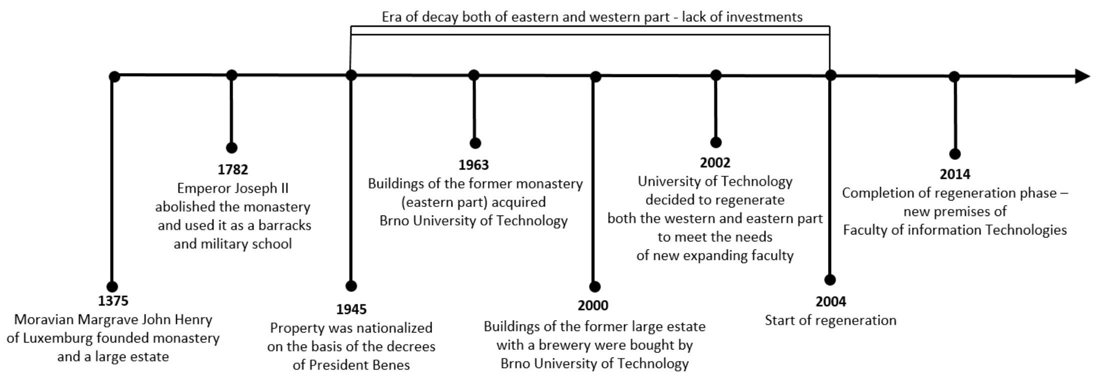

Figure 9. Timeline of the key milestones of the development of the studied regeneration project. Source: Authors' own processing.

2.2. Data Collection

Our methodology is principally entrenched in the analyses of the information gathered during interviews with seven informants that were complemented by the study of collated written materials. The interviews were conducted in the first half of 2020. The interviewees were selected to represent diverse actors involved in the regeneration project (please see Table 3). All our interviews were carried out with the physical participation of both parties (online interviews were avoided) and lasted for circa two hours. All seven interviewees provided their consent to use their ideas and opinions in our research. We thoroughly informed all participants about the aims of our research, our funding, and also how the information provided will be secured so that any misuse of confidentiality is avoided. All interviews were recorded after consent. The oral recordings were subsequently transcribed and the transcripts coded and analyzed using the Atlas.ti software. To avoid any breach of anonymity, the personal information of the interviewees was stored separately in an offline repository.

Table 3. Basic characteristics of the interviewed communication partners involved with the regeneration project.

Communication Partner	Sex (F/M)	Education	Age Category (Years)	Position
No. 1	M	University	50–60	Archaeologist
No. 2	M	University	50–60	Art historian
No. 3	M	University	60–70	Architect
No. 4	M	University	50–60	Vice dean for development
No. 5	M	University	50–60	Mayor of city district Brno—Královo Pole
No. 6	M	University	40–50	Expert on brownfields regeneration
No. 7	M	University	60–70	Former student

Source: Authors' own processing.

3. Results

3.1. Gradual Decline of the Site during the 20th Century

The beginning of the transformation of the site from mostly agricultural to mostly urban fell in the period of the First Czechoslovak Republic, when in 1919, as part of the creation of Large Brno, Královo Pole was administratively amalgamated with Brno. According to an archeologist: "The large estate in Královo Pole functioned basically until the time of the First Republic. Land reforms of the 1920s basically allowed large landowners to interfere with the things here. However, the lands were redistributed to several owners. ... The cessation of agricultural production in the area went hand in hand with the land reform and the development of the agglomeration, which was basically turning from agricultural to industrial ... It's basically a specific form of that agricultural brownfield, because it then developed within, like, an urban environment".

In the period after 1945 the site was completely nationalized. The Communist Party had little respect for religious buildings so plenty of churches and monasteries in many places in the former Czechoslovakia were dilapidated. Fortunately, the former monastery in Brno was in a better position, because in 1963 it was handed over from the state ownership to the Brno University of Technology. The Vice Dean for Development of the university commented on this phase in the following way: "The Brno University of Technology acquired the site as a replacement for the buildings that had been confiscated by the military academy ... In 1963 the Brno University of Technology acquired the premises as it was expanding its activities. Two departments, the then Faculty of Electrical Engineering, namely the Department of Automatic Computers and the Department of Automation, were relocated here from the city center. ... The Technical University got that campus in very bad, derelict shape". The mayor of city district where the site is situated described the era in the following way: "Basically, from 1963 to 1992 ... the university had a million here and there, which wasn't even enough money to provide for all the repairs of the property".

Brno University of Technology attempted to progress with the redevelopment, but at that time, public universities suffered from a huge lack of funds for their development. In other words, most of the funding was devoted just to the emergency maintenance of the site. The utilization of the former monastery, which had served many other purposes in the past, was complicated. Sometimes even the tuition took place in these premises, which were far from ideal. A former student described this situation: "When I managed to enter this university in 1967 as a student and we had these lectures in the former stables of the monastery, it was in one of those buildings where there was a stone trough ... 200 people were supposed to fit in this room ... They did fit in, but only the first 10 rows could hear and the others played cards".

The western part of the site, which was traditionally used for processing agricultural crops, was used in various ways during the socialist era, for example, for ripening exotic fruits or as a vegetable store. Some forms of other temporary uses have been more successful and others less so, which the mayor of the city district commented upon: "There was a glass shop, there was a butcher shop that was in substandard conditions ... yeah, it was in disrepair as it was ... but there was a famous pub in those former goat sheds that was very popular ... ".

3.2. Regeneration Process and Related Issues

In the 1990s, Brno underwent an extensive transformation of its economy from a centrally planned to a market economy. This period was typified by the bankruptcy of many industrial and agricultural enterprises and the rapid growth of the service sector. State support for public universities was increased during the 1990s, which enabled investments in the redevelopment of the university's real estate. In line with these trends, the number of students began to increase at the Faculty of Information Technology at Brno University of Technology. The Vice Dean for Development commented on the state in the following way: "We had to solve the question of how to ensure the further development of the faculty ...

whether we will move to the area under Palacký Hill on the outskirts of Brno or stay here in Královo Pole, but in that case we have to use the area of the former large estate".

In the 1990s, the western part of the case study area was owned by the city, a situation the Vice Dean for Development described as follows: "So the crucial meeting was with the former mayor, who agreed with the idea of the Faculty further developing here and even said that it would be a lifesaver for the monastery, because until then we were always looking for money and it always ended up that we got a couple of million, but a couple of million here in this whole area is like spitting in the sea, yeah. It required an investment of about 800 million CZK here". When the university became the owner of the western part of the case study area in 2000, it was the first crucial step on the road to the regeneration of the site, but number of other issues still had to be solved.

To enable the regeneration project of a former monastery, an archaeological survey had to be carried out first, which caused another delay. A survey is obligatory in areas with archaeological findings under the State Heritage Protection Act. According to the archeologist: "An investor who wants to build in such an area must notify the archaeological institute of his intention well in advance and then make arrangements with an authorized organization to carry out archaeological excavations". Furthermore, a project for the preservation of the architectural heritage was drawn up and, in a cooperation with the heritage protection authority, the buildings that could be removed and modified were identified. The most valuable parts of the former monastery were also detected, namely a large square cell with the buildings surrounding the church, as well as the administration building of the manor house (the headquarters of the former large estate) and the brewery (former malt house) with the cellars declared a monument on the basis of a structural and historical survey. However, the entire farmyard was not identified as a valuable historical monument.

From an architectural point of view, two options were discussed. The first option was that the buildings would be reconstructed and given their original appearance, the second option was a combination of old architecture with modern architecture. It was decided to go with the second option. The Vice Dean of Development advised that "the historic core was being reconstructed to the form that the preservationists had established and on the other side of the street a combination of modern architecture with glass cladding, soundproofed, and that laboratory triple tract in the back, that's where the poster concrete is used". In addition, the architect mentioned that "technical solutions had to be sought in the project preparation to avoid various problems; for example, the original monastery is on some wooden piles, and if we were to dry out the underground it could destroy the system".

In the whole regeneration concept, some buildings in the agricultural yard were demolished and replaced by new buildings. According to the architect, "the new buildings made it possible to make some acceptable economics of the construction for society. So, from that point of view, it was really quite successful in tuning it and the money came into the area". The farmyard was therefore less protected than the monastery and so more intervention could be made. For example, the north and south cloisters could not be used for anything other than administration purposes. On the other hand, in the area of the former farmyard "heavy laboratories could be built, which could not be done in a monastery because we would damage what is left here" (Vice Dean for Development).

3.3. Evaluation of the Overall Regeneration Result

It can be concluded that the vast majority of actors evaluate the outcome of the regeneration positively. According to the archaeologist, it is the only representative preserved medieval Carthusian monastery in the Czech Republic, whose revival was carried out with the help of an acceptable intervention of an architect who sensitively integrated his work into the area. He also said with exaggeration that "if something is not sacrificed, then it is impossible to invest in the rest. We have a beautifully preserved and quite well restored monastery with a little big quadrangle, the part of the big courtyard by the street. Well, but that's sacrificed the buildings in the farmyard. I think it's so that the faculty can be housed there and somehow function on some level; it worked out well". Beyond this, he considers the conversion a successful demonstration that even a 21st century institution can function in a historic site with respect for the original layout and cultural and historical value of the site. From the point of view of heritage values, the interviewed architect believes that the most valuable parts of the buildings have been restored to such an extent that they will be preserved for years to come.

According to the Vice Dean for development, "the result is an A-star because the Faculty is here; the Faculty was established in 2002 and has been here ever since". He further informed that there is currently so much interest in studying at this faculty that it exceeds the stated capacity and therefore he thinks that what was set out at the beginning of the project has been achieved. In his opinion, "this is one of the most beautiful and best functioning campuses within higher education in the country. I dare say that, yes, maybe the world, I would say that as part of the preservation of architectural heritage, it has been possible to build a campus that is unparalleled in the Czech Republic today and goes beyond".

The architect was also very positive about the overall result, "as the school is still functioning in these premises and the historic buildings or the original agricultural ones have a new, meaningful use ... so this is certainly a good example". He also mentioned that what was set out at the beginning of the project has been achieved, as people from the surrounding area, conservationists, and the professional and architectural community have all received the building positively. According to the mayor, "an exceptional university facility has been built, which in his opinion has been positively evaluated by the public, as there were many people who wanted to see the newly opened campus during the open day".

Critical assessments of regeneration were rather rare, but in some cases quite harsh criticism was voiced. The art historian sees the project as a frightening example of how a society's relationship to its cultural heritage can fail and stressed that "the university does not have to act as an educational, cultural institution that is supposed to be a natural role model for students and the public but can fail in a particular matter". The art historian further thought that it was not appropriate to build new buildings on the site. In his opinion, the farmyard was the site of "the deliberate destruction of a cultural heritage, the destruction of an entire urban plan, the destruction of a genius loci, an intervention that significantly contributed to the destruction of the core of one of the historic settlements that merged with the city of Brno".

4. Discussion

4.1. Main Supporting Factors Related to the Regeneration

As a part of our research, the main factors that supported the regeneration of the site were identified. The Vice Dean of Development identified the fact that the site was owned and managed by the city administration as an important factor enabling the success of the project ("if the buildings had been in private hands the University may not have been able to acquire the site"). He also stressed that if the university had not stayed on the site, it is unlikely that the funds would have been found to renovate the former monastery site to its present form. Both the mayor and the Vice Dean of Development agreed that the most important factor that influenced the regeneration was that there was a synergy of interests. On the one hand, the university's interest in further development, and on the other hand, the city's interest in retaining students and their purchasing power within this urban area in the Brno city district.

The mayor further stressed that when revitalizing old buildings, it is necessary to know the complete future use of the target condition, because "if I don't have this future use and it is not adapted to those decades' later conditions, then unfortunately everything goes bankrupt". In this context, the mayor further noted that it is very difficult to find a meaningful use for old historic buildings that would fit the conditions of today's modern world: "It is hard to find a solid infill from today's life without very significant structural changes. The historical buildings have some value but to give it a contemporary infill or a contemporary life is extremely difficult and of course the college is a wonderful idea". According to the architect, one must consider "the consistency of that contemplated infill with that location", so that the nature of the campus is consistent with the nature of the use and the campus has some purpose that can continue in future.

According to the archaeologist, finances are the most important factor, but "if one does not rush, one can try to repeatedly apply for various projects; public funds are relatively accessible, whether from the European Union, the state, Norwegian funds, etc.". The art historian expressed a similar view, stating that in addition to the relationship with the place, funding is also important for regeneration, but if there is no money, he said, one must learn how to get it. In addition, he considers that another factor that contributes to the regeneration of disused buildings is the motivation and ability to motivate other people to help with the regeneration process.

The supporting factors were analyzed using ATLAS.ti software and the list of the most important factors (Table 4) shows that a well-thought-out vision together with the interest of the stakeholders were the main circumstances that influenced the success of the regeneration. According to the communication partners, the support and interest of the institutions was another crucial condition for the regeneration of the site to take place, as their approval was needed to make such a large investment. According to [41], if the premises have been dilapidated for a long time, it could have been expected that their redevelopment would not be likely, and demolition would remain the only possible solution. However, this fact was not confirmed in the given location, as an important reason for which the regeneration took place was the historical value of the selected buildings (monastery, administrative building of the estate, malt house), for whose restoration and preservation for the future the promise of individual subsidy support from the Ministry of Finance was necessary.

Table 4. Information about the main identified supporting factors of the regeneration process related to the case study area.

Code No.	Supporting Factors	Frequency	Description
1	Clear Future Use	27	A coherent vision to address the growing interest of students in information technology.
2	Stakeholders' Cooperation	22	A well-developed project and intensive cooperation between capable stakeholders.
3	Political support	19	Support of the urban district, the city, from individual ministries.
4	Historical value	17	Saving part of the most valuable architectural heritage and preserving the historical character of the selected buildings.
5	Public funding	12	The promise of an individual public subsidy in relation to the value of the whole area.

Source: Authors' own processing using ATLAS.ti software (Scientific Software Development GmbH, Berlin, Germany).

4.2. Main Barriers to the Regeneration of the Site

During our research, attention was also focused on the most important barriers that had to be overcome. The barrier, according to the Vice Dean of Development, was poorly conducted research of the site, which led to the need to incur additional costs for more work. Another problem was that this was a very valuable area in terms of potential finds, so construction was often complicated by archaeological surveys, but according to the Vice Dean of Development this fact was taken into account. In the case of the administration building of the large estate, which, apart from the malt house, had to be preserved, the conservation authority insisted that it had to be restored to the form in which it had been built. "That means the castellated windows; there was only one, otherwise it was all broken and we had to make all those castellated windows, one window for 80,000, and it didn't have the brackets yet, but I don't regret the money; those were complications that we had to sort of solve in the end by running around and getting the money for it, because they don't fall down by themselves, do they?" (Vice Dean of Development).

According to the archaeologist, the archaeological excavations did not bring any serious problems, because "Basically, apart from the time and money that the archaeology costs, which the investor was aware of and was accommodating in this, I don't think they had any problems. Of course, it was sometimes on the edge of the deadline, but, well, that's the way it is". There were some finds that were discovered that were not known about, but the investor accepted these finds with respect for the property. A 17th century ceiling was discovered above the library, and a "17th century walled toilet at the corner by Bozetechova Street; they still have it there, yes, there was even a toilet seat, everything was there, and it's dated by dendrochronological method". In the farmyard, the construction was again complicated by the discovery of a 14th century brick kiln, according to the archaeologist "they may have waited for us for a while, but these are such small things, marginalia, and in the end it did not affect the construction date at all".

Parking also had to be built on the campus and "We did not want to have plenty of parking spaces in the courtyard. So we decided to build underground parking". (Vice Dean of Development). Thus, major problems arose when the depth surveys were done, as there was groundwater that made it difficult to build several hundred parking spaces for students and staff at the school. "Unfortunately, we only got one underground floor below ground level because if we had gone deeper there would have been pressurized ground water, which would have been a problem in terms of cost" (Vice Dean of Development). Therefore, there are only 250 parking spaces underground, the remaining spaces are above ground.

In this context, the architect noted that there are always things that are not foreseen on the construction site; according to him, the most complex and the biggest problem that complicated the course of the regeneration was groundwater and insufficient funds that had to be secured to supplement the financing of some buildings for the main parts of the reconstruction. The mayor also considered finance to be the biggest critical point and in this regard he stated that "given that it is an educational facility and it will have many years of use, no one could probably raise the same amount of funds to fix the historic buildings of the monastery for any other purpose". The mayor went on to say that the historic buildings needed complete renovation and incorporation into viable urban functions, and in his opinion, that would require a significant amount of funding that a private entity could not raise in a normal world. The Vice Dean of Development agreed with this view, pointing out that "there was support from all sides, that is, from the Ministry of Culture, from the municipality, and from the education department, but the biggest role in this was then played by the Ministry of Finance in terms of actually covering it and being willing to cover an investment of this magnitude".

Regeneration barriers were also analyzed using ATLAS.ti software and the list of the most important barriers (Table 5) shows that one of the barriers to the new use were the property relations related to the profit of the farmyard. In addition, according to respondents, there were problems with the procurement of funds. This is in line with the findings of [54,55], which considered poor technical conditions of buildings to be a barrier to regeneration. Our respondents also agreed that complications were brought about by poorly conducted surveys and the compromised statics of the buildings [56]. In addition, the respondents also saw a problem in the conditions of conservation. According to the respondents, groundwater, which was a particular problem for the construction of parking spaces, was also considered an obstacle, and last but not least, there were difficulties with people who were against the demolition of some buildings.

Table 5. Information about the main identified barriers to the regeneration process related to the case study area.

Code No.	Barriers	Frequency	Description
1	Property relations	15	Different owners of the western and eastern part at the beginning of the process.
2	Financial resources	14	Lengthy negotiations in an attempt to secure funding for such a financially demanding project.
3	Technical state	13	Poorly carried out building survey and disturbed statics of buildings leading to additional costs.
4	Monument care	12	Complications arising from the archaeological survey and conservation orders of many buildings.
5	Public grant	12	The promise of an individual public subsidy in relation to the value of the whole area.
6	Underground water	8	Flooded cellars in the western part of the site and problems with groundwater during the construction of parking spaces.
7	Public comments	8	Protests by some people against the demolition of certain buildings; various concerns and complaints from certain individuals.

Source: Authors' own processing using ATLAS.ti software (Scientific Software Development GmbH, Berlin, Germany).

5. Conclusions

Our findings indicate that de-agrarianization on the outskirts of large cities usually takes place in several phases (please see Figure 10) that are highly context-specific; however, several commonalities undoubtedly might be identified. First, agricultural land is taken for new urban development and agricultural properties lose their use. Second, agricultural properties are used without major investment interventions, but often continue to be utilized to store agricultural products from more distant locations, regions, and countries (in our case study, for example, as a vegetable store and a tropical fruit ripening facility). Third, most of the obsolete agricultural properties are being replaced because they do not meet the requirements for the development of new urban functions. In our case study area, only the former malt house and the former administration building of the large farm have been saved and the other buildings have been demolished. If we turn back to the findings from our case study, the preservation of the former monastery was given a priority over the preservation of most of the buildings of the former agricultural estate. From a symbolic point of view, it is interesting that the monastery, which in the Middle Ages served as a center of knowledge and dissemination for innovative farming methods, has been replaced by a technical university, where a focal point can be seen in the knowledge-based economy.

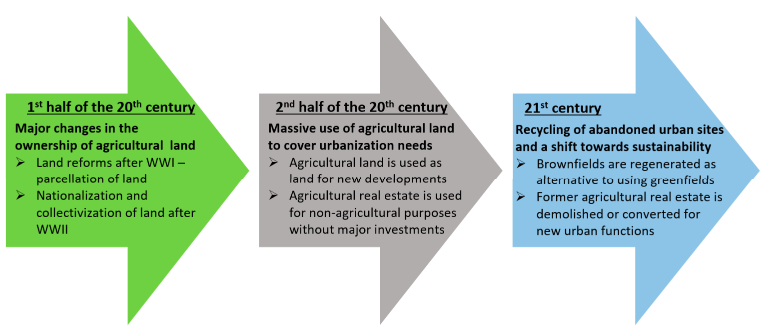

Figure 10. Stages of de-agrarianization and urban renewal in a post-socialist city. Source: Authors' own processing.

Author Contributions: Conceptualization, P.K. and K.C.; methodology, K.C. and P.K.; formal analysis, K.C., P.K., S.M. and J.N.; investigation, K.C. and J.N.; resources, P.K.; data curation, K.C. and S.M.; writing—original draft preparation, P.K. and K.C.; writing—review and editing, P.K., S.M., K.C. and J.N.; visualization, P.K., K.C. and J.N. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the project Specific Factors of Competitive Development at Regional and Local Level MUNI/A/1406/2021.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: We are grateful for the opinions and ideas of anonymous reviewers about our work.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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Management of Landslides in a Rural–Urban Transition Zone Using Machine Learning Algorithms—A Case Study of a National Highway (NH-44), India, in the Rugged Himalayan Terrains

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Citation: Fayaz, M.; Meraj, G.; Khader, S.A.; Farooq, M.; Kanga, S.; Singh, S.K.; Kumar, P.; Sahu, N. Management of Landslides in a Rural–Urban Transition Zone Using Machine Learning Algorithms—A Case Study of a National Highway (NH-44), India, in the Rugged Himalayan Terrains. *Land* **2022**, *11*, 884. https://doi.org/10.3390/land11060884

Academic Editors: Carmen Delgado Viñas and María L. Gómez-Moreno

Received: 29 April 2022
Accepted: 7 June 2022
Published: 10 June 2022

Abstract: Landslides are critical natural disasters characterized by a downward movement of land masses. As one of the deadliest types of disasters worldwide, they have a high death toll every year and cause a large amount of economic damage. The transition between urban and rural areas is characterized by highways, which, in rugged Himalayan terrain, have to be constructed by cutting into the mountains, thereby destabilizing them and making them prone to landslides. This study was conducted landslide-prone regions of the entire Himalayan belt, i.e., National Highway NH-44 (the Jammu–Srinagar stretch). The main objectives of this study are to understand the causes behind the regular recurrence of the landslides in this region and propose a landslide early warning system (LEWS) based on the most suitable machine learning algorithms among the four selected, i.e., multiple linear regression, adaptive neuro-fuzzy inference system (ANFIS), random forest, and decision tree. It was found that ANFIS and random forest outperformed the other proposed methods with a substantial increase in overall accuracy. The LEWS model was developed using the land system parameters that govern landslide occurrence, such as rainfall, soil moisture, distance to the road and river, slope, land surface temperature (LST), and the built-up area (BUA) near the landslide site. The developed LEWS was validated using various statistical error assessment tools such as the root mean square error (RMSE), mean square error (MSE), confusion matrix, out-of-bag (OOB) error estimation, and area under the receiver operating characteristic (ROC) curve (AUC). The outcomes of this study can help to manage landslide hazards in the Himalayan urban–rural transition zones and serve as a sample study for similar mountainous regions of the world.

Keywords: hazards; early warning system; LST; urban–rural fringes; machine learning; ANFIS; random forest; decision tree

1. Introduction

Landslides are a type of mass movement on the steep slopes of rugged landscapes and can take several forms, such as rockfalls, mudslides, and debris falls. Landslides are triggered by both natural and anthropogenic activities [1,2]. Extended heavy rainfall events, earthquakes, soil properties, and changes in groundwater level are some of the natural causes behind landslides. In contrast, heavy traffic near the landslide susceptible site, tunnel construction, excessive mining and quarrying, and cutting of steep hills for road construction or widening are some significant anthropogenic factors that have made slopes extremely vulnerable to failures [3]. All these factors can be responsible for single or multiple slope failures on the hill slopes [4].

Globally, landslides cause a large amount of destruction to the lives and property of millions of people living in regions vulnerable to landslides. About 55,997 deaths have been reported worldwide due to 4862 landslide events between January 2004 and December 2016, and most of them occurred in Asia alone [5]. Moreover, due to the destruction of roads and industrial establishments, landslides are responsible for considerable losses to the economy of the regions. The Reventador landslides in Ecuador (Napo) killed one thousand people and caused a colossal economic loss of about 1 billion dollars [6]. Alaska's landslide in 1964 caused a financial loss of 280 million dollars [7]. The Haiyuan landslides in China (Ningxia) killed 100,000 people, destroyed many villages, and caused a substantial economic loss in 1920 [8]. Landslides are also responsible for causing landslide lake outburst floods, a widespread phenomenon in the Himalayas (LLOF) [9,10]. LLOF is caused when a landslide blocks a stream or a river and forms a temporary pool-like situation. The accumulated water increases the pressure on the obstruction, which eventually is breached and gives way to the accumulated water [11]. According to recent studies, the outburst can release millions of cubic meters of water in short limited time intervals, creating a situation similar to a Glacier Lake Outburst Flood (GLOF) [12]. An LLOF struck Chamoli, Uttarakhand, India, on 7 February 2021, claiming 72 lives, and causing extensive damage to a power construction project.

The Himalayan regions are mainly characterized by sparsely separated urban and rural settlement zones [13]. The transition between these zones often involves the large mountainous belts that have to be cut in order to pave the way for the movement of people and supplies [14]. The highways constructed along these transition zones, because they destabilize the mountain slopes, are one of the factors causing this region to be vulnerable to landslides [15]. Understanding the processes initiating landslides is extremely important in the Himalayas as people's lives are dependent on their occurrence. One major scientific stride in the assessment of landslides is predicting their occurrence. In this context, machine learning algorithms have been at the forefront of scientific development [16–19]. ML uses algorithms to learn from past data patterns to produce insights into future extreme disaster events [20], such as decision tree, artificial neural networks (ANN), and statistical regression analysis. These techniques can learn patterns and associations between the responsible factors and disaster occurrences without an anticipated structural model [21]. In disaster and hazard management, machine learning models are now used to augment the traditional field-based methods, as they provide the inputs for greater accuracy and prediction capabilities [22]. ML has shown remarkable results in hazard prediction, with the ability to collate more variables as causal factors for better analysis and precise predictions [23]. Moreover, they have proved to be a convenient option for handling big-data spatial analytics, when the theoretical approaches to a problem are insufficient [24], and statistical pre-assumptions are inconsistent or unknown [25]. With these characteristics and its resilience as one of the best methods for dealing with nonlinear geo-environmental challenges, ML techniques are increasingly being applied to determine different hazard predictions [26]. Many machine learning algorithms have been used for landslide susceptibility mapping utilizing internal (geological, topographical, and environmental) parameters in the Himalayas [27–30]. Not much work has been performed in landslide prediction modelling using ML in this region, and prediction is one of the main components of disaster mitigation.

In the present study, we explore the use of Machine Learning (ML) algorithms for predicting the landslides of one of the hard-hit landslide-prone areas of the Himalayas, the NH-44 national highway, Jammu–Srinagar stretch, India, specifically, the northernmost segment of NH-44 that extends over 65 km from the Jawahar Tunnel to Chandarkote. It connects the Kashmir valley with the rest of India, passing through the highly steep and unconsolidated slopes of the northern Himalayan Mountains. The highway's significance lies in the fact that it is considered the bloodline of the Kashmir valley since all the daily supplies to the valley have to pass through it [31]. Climatologically, this area receives a monthly average rainfall of 75–150 mm, which is responsible for heavily saturating the soil on the slopes and causing slope failures [32,33]. Most of the landslide events in this area take place during or immediately after a heavy spell of precipitation. Every year, the whole Kashmir valley and the UT of Leh and Ladakh are adversely impacted in terms of the loss of human lives and damage to the economy due to landslides on this segment of the NH-44 Highway [34]. Nearly 8000 accidents and 2000 deaths were recorded on this highway between 2000 and 2010 [35]. Further, according to the Kashmir Traders and Manufacturers Fund (KTMF), the economic losses to the Kashmir valley approximate about 50 million rupees due to the continuous blockage of the National Highway. In this context, it is essential to holistically understand the causes of the landslides and use that knowledge to develop and design an advanced landslide early warning system (LEWS) for this region that can predict landslides before they hit the area to save life and property. The main objective of this paper is to propose an efficient landslide prediction model for better and more precise landslide prediction. Using field and satellite-based data, we compare four highly efficient machine learning prediction modelling algorithms (multiple linear regression, adaptive neuro-fuzzy inference system-ANFIS, random forest, and decision tree) to determine which is the best among these for a LEWS at the Jammu–Srinagar National Highway, NH-44.

2. Study Area

The study area is shown in Figure 1 and is located between the Ramban and Banihal district of Jammu and Kashmir, belonging to the northern Himalayas with an altitude of 495–4510 m above sea level. The area covers an area of 401 Km^2 and extends over a distance of 65 km from the Jawahar Tunnel to Chandarkote. Such regions in India are known to be highly vulnerable to landslides [36], since many landslides have occurred in the past, and more than ten highly significant and devastating events occurred between December 2020 and January 2021. The area has hilly topography with an average altitude of 2044 m above mean sea level, making it an area highly prone to landslides.

The study area is located between two different climatic regions. The Jammu region has a subtropical climate, while Kashmir has a moderate climate. The Ramban region in the study area belongs to the Jammu division, while Banihal belongs to the Kashmir division of the state of Jammu and Kashmir. The temperature of the study area ranges from −5 °C to 30 °C over the Banihal region. In contrast, the Ramban region has a minimum temperature of approximately 5–10 °C and the maximum may reach 38 °C in summer [37]. The study area has a lowest altitude of 495 m and a maximum of 4510 m above mean sea level. The road corridor has a minimum of 1150 m and a maximum of 2200 m elevation above the mean sea level, making the slopes along the National Highway highly vulnerable to land failures and rock slides [38]. One of the landslide sites is shown in Figure 2. Because of the high elevation, the area receives high-intensity rainfall in January, April, June, August, and December, with an average of 330 mm per month. The daily mean precipitation (TRMM data) of the study area from 2000 to 2020 is shown in Figure 3. It clearly shows extreme precipitation events throughout the year and for each year during the observation period.

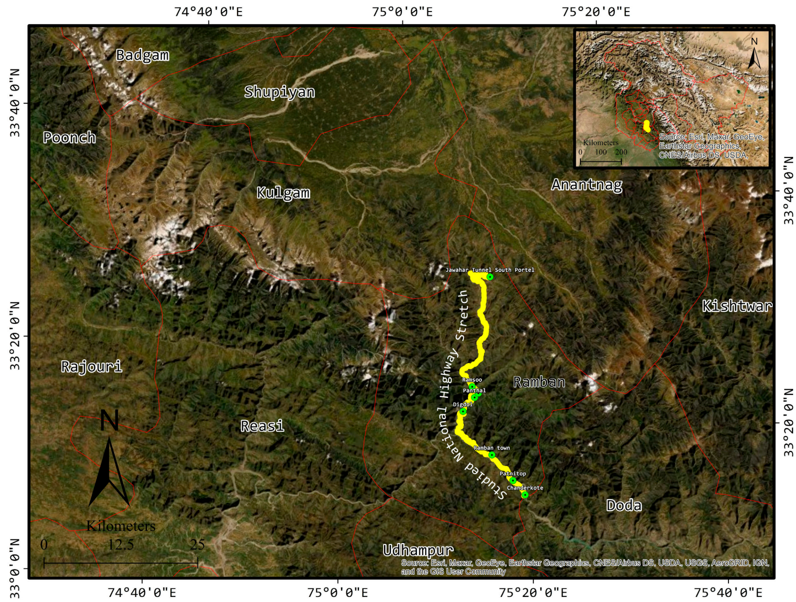

Figure 1. Location map of the National Highway NH-44 stretch studied in this paper. The upper right inset is its location with reference to the UT of Jammu and Kashmir, India. The red outlines are the districts of the UT of J and K. The green dots on the National Highway are the prominent landmarks as well as the sampling points. The map coordinates are in the UTM 43 (North) World Geodetic System (WGS-1984) reference system.

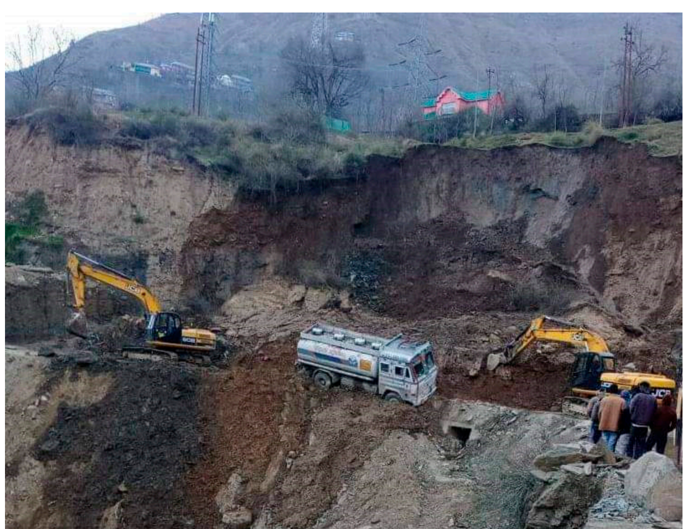

Figure 2. Prominent landslide site at Ramban along the NH 44.

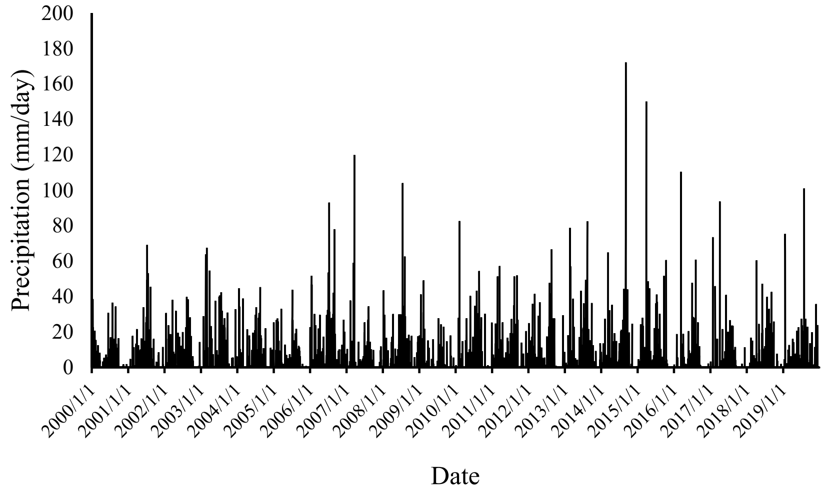

Figure 3. Daily mean precipitation of the study area from 2000 to 2020 based on the Tropical Rainfall Monitoring Mission (TRMM) data.

3. Materials and Methods

3.1. Field Observation and Data

Field observation is an effective procedure for landslide hazard assessment to collect the primary field data (distance to road, distance to river, and general evaluation of the location) for the study [39]. The mapping and landslide susceptibility analysis of landslide-prone areas is the first stage in the field observation [40]. As part of the research, a field investigation was conducted in October 2020. The objective was to physically examine and analyse landslide hotspots to collect the data required for spatial landslide prediction. During the field observation, around 258 spots were identified. Based on the slope, proximity to habitation and roads, vegetation cover, and soil parameters, we classified them into three classes. Out of the 258 spots, 49 were highly active, 59 were medium prone, and 150 had a low potential for a slide in the near future.

The distance to the road and the distance to the river, which can influence slope stability, were obtained using the base map services from ArcGIS 10.4.1. Some sites were measured manually with measuring tape, as shown in Figure 4. The landslide inventory of the study area was obtained from (Global landslide catalog) svs.gsfc.nasa.gov (accessed on 1 December 2021) and from local sources (newspapers, social media, and online news reports). Some soil characteristics and threshold values were derived from Fayaz and Khader (2020) [41]. The same threshold values were used to predict landslides using machine learning methods (algorithm). Slope angle data were obtained using a mechanical tool inclinometer and a Digital Elevation Model (DEM) generated from stereo SRTM DEM. The rainfall data were divided into four categories for better model predictions and accuracy: (i) 0–20 mm as '1', (ii) 21–40 mm as '2', (iii) 41–100 mm as '3', and (iv) a 3-day antecedent rainfall above 50 mm as '4'. The area-average of the root zone soil moisture in kgm^2 was obtained from NASA (giovanni.gsfc.nasa.gov (accessed on 01 December 2021)) using [GLDAS Model GLDAS_CLSM025_D V2.0]. The built-up area near the landslide spots was measured and calculated using ArcMap 10.4.1. The structures (construction) surrounding each landslide-prone site were mapped with ArcGIS Basemap services and measured in square meters. Table 1 shows the sources of the data used in the present study.

Figure 4. Field photographs while collecting data for model parameterization.

Table 1. Data used in this study along with their sources.

Data	Source
Rainfall (RF)	TRMM giovanni.gsfc.nasa.gov (accessed on 21 June 2021)
Land Surface Temperature (LST)	giovanni.gsfc.nasa.gov (accessed on 21 June 2021)
Slope Moisture (SM)	giovanni.gsfc.nasa.gov (accessed on 21 June 2021)
Slope Angle (SLP)	Slope Map and Manually using Inclinometer
Distance to Road (DTRD)	GIS and Manually using Measuring tape
Distance to River (DTR)	GIS and Manually using Measuring tape
Built-up Area (BUA)	Visual Image Interpretation using ArcGIS Basemap services

3.2. Methods

In this paper, a landslide prediction model was designed using various machine learning algorithms. The algorithms used were Multiple Linear Regression, Adaptive Neuro-Fuzzy Inference System (ANFIS), Random Forest, and Decision Tree; the model accuracies were compared to determine the optimal prediction system for landslides. The application of these models in landslide engineering has been discussed in detail by Fayaz and Khader (2020) [41]. The overall methodology used in the present study is shown in Figure 5.

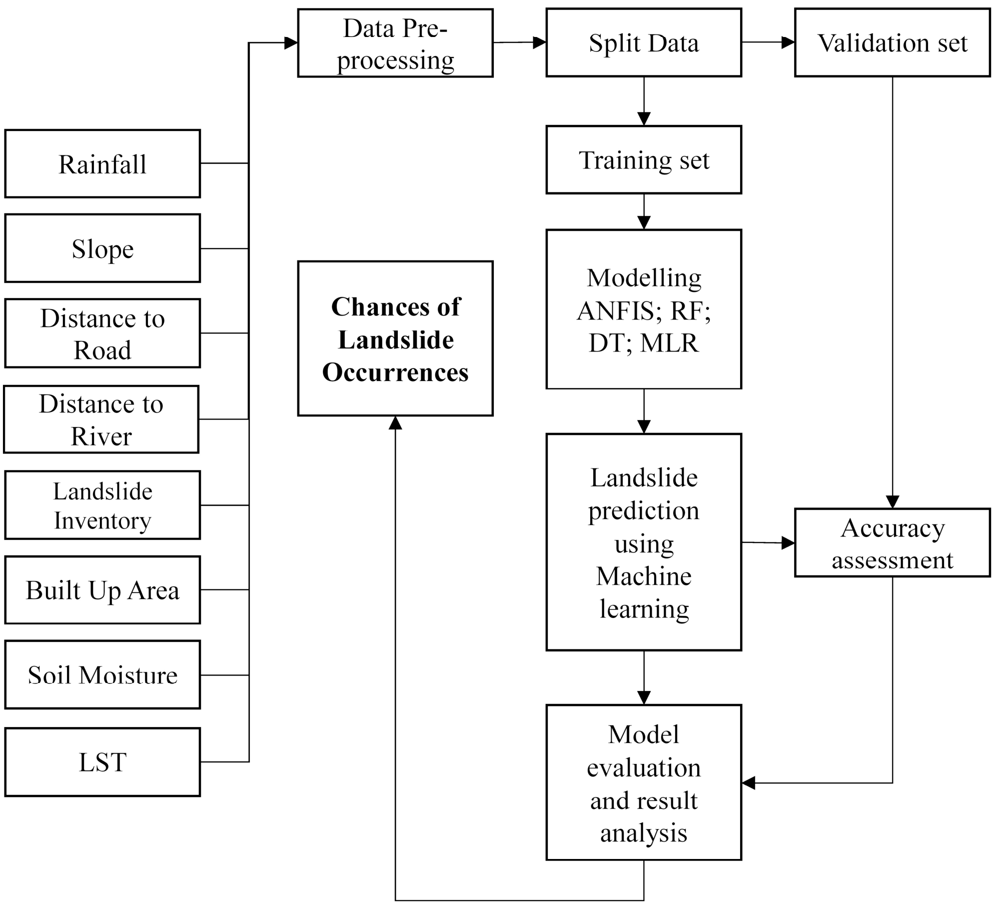

Figure 5. Flow chart of the overall LEWS framework used in the present study.

3.2.1. Multiple Linear Regression (MLR)

Multiple linear regression (MLR) was used to predict the chances of landslide in the range of (1–3), where 1 is low, 2 is medium, and 3 is high.

The population regression line for the explanatory variables $X_1, X_2, X_3, \ldots, Xn$ is defined as

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_5X_5 + b_6X_6 + b_7X_7 + \varepsilon,$$

where

Y = dependent variable (predicted value).
b_0 = 'constant' (Y intercept), which is the value of Y when all the independent variables are zero.
X_1 through X_7 = predictor or p distinct independent variables.
ε is the aspect of the random error that reflects the difference between the predicted and fitted linear relationship; b1 through b7 are the estimated regression coefficients, which are estimates of the unknown population parameters explaining the correlation between the output response and dependent variable [40].

The MLR model statistics were used to determine the contribution of the variables to the overall model. It is important to determine the percentage of importance of each independent variable and specify whether the variable in the model is really contributing significantly or not. The independent *p*-values of the variables were reviewed to determine whether or not all the variables were statistically significant [42]. All the independent variables used in the model were found to be significant, while the newly added variables of LST and BUA (Built-up Area near the prone site) were both found to be highly significant. The *p*-values of the model coefficients for the variables were evaluated; the *p*-value of the LST was 8.40×10^{-5}, which is nearly 99.99%, and the BUA was $<2 \times 10^{-16}$, which is very close to 100%. Therefore, the results indicate that both the variables were highly significant for the Landslide Prediction System.

The model was initially tested without the newly incorporated (LST and BUA) variables using the 'l' function in R-Programming. It showed a 95.79% significance (Accuracy), with a Multiple R-squared of 0.9579 and an Adjusted R-squared of 0.9565. The accuracy was improved further from 95.79% to 98.27% by including the new independent variables, which implies that the variables are important and significant for landslide prediction and the Early Warning System.

The overall significance statistics of the final improved model were calculated as follows: the variance, also known as the Mean Square Error (MSE), was estimated using Equation (1) [43].

$$s^2 = \frac{\sum_{ei} 2}{n - p - 1} \quad (1)$$

The residual standard error was 0.1275 on 151 degrees of freedom; the Multiple R-squared was 0.9827, the Adjusted R-squared was 0.9819; the F-statistic was 1223 on 7 and 151 DF, and the *p*-value was $<2.2 \times 10^{-16}$.

The variables in the model contributed 98% to the overall model with an F-statistic of 1223 on 7 and 151 DF and a '*p*-value' of 2.2×10^{-16}, which is equal to 1–2.2×10^{-17} and approximately equivalent to 100%. The F-statistic is a value used to determine if the means between two populations are significantly different [44]. The F-statistic from an F-Test is similar to the T statistic from a T-Test [45]. The T-Test is used to find whether a single variable is statistically significant, while an F statistic is used to see if the group of variables are jointly substantial [46]. The F statistic must be used in combination with the *p*-value to determine if the overall results are significant. The *p*-value must be less than the alpha level, which is 0.05 for the standard test; otherwise, the null hypothesis cannot be rejected [47].

3.2.2. Decision Tree (Classification Tree)

A Decision Tree (DT) is a type of supervised machine learning algorithm where a system generates output based on the training data (input and output) given to the model [48]. The data are classified based on the various parameters and their importance in the overall model [49]. The top node of the model represents a highly significant and highly contributing variable, then a second one, and so on [50]. The two entities, leaves and decision nodes, explain the tree, where the leaves denote results or the outcome, and the decision nodes represent the nodes where the decisions are made [51]. It helps to make excellent decisions/interpretations at every leaf based on the previous experience (data). It clearly mimics human-level thinking and decision making [52]. The classification type of a decision tree with five terminal nodes is shown in Figure 6, and it was used to classify and interpret the chances of landslides based on the training data.

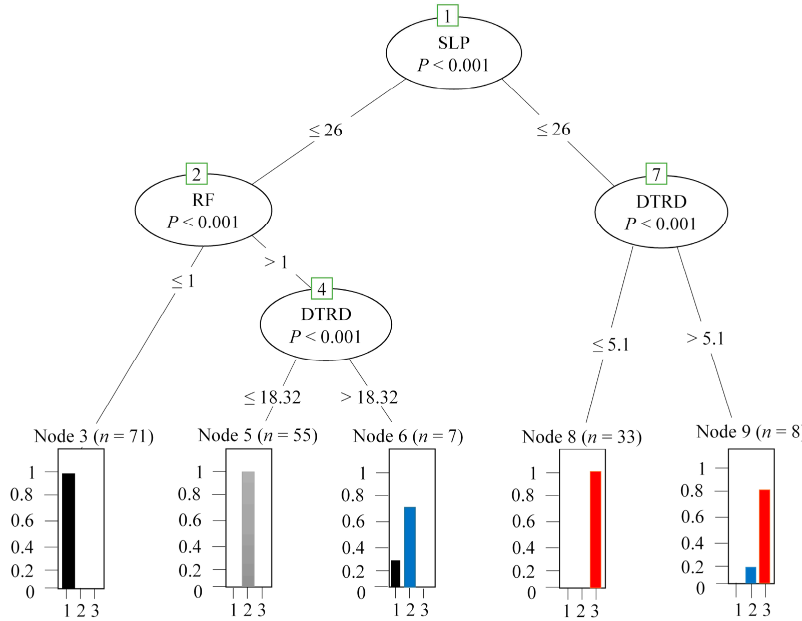

Figure 6. Classification and interpretation of the chances of a landslide based on the training data using the decision tree algorithm.

The data were divided at the first node (SLP), which, according to the DT, is a highly significant and highly contributing attribute to the overall model. The data at the first node were split into two groups, data with an SLP value less than or equal to twenty-six and data with an SLP value greater than twenty-six. Data with an SLP value greater than twenty-six were then distributed into two on the basis of the DTRD (Distance to Road), whether the data point was less than or equal to 5.1 or greater than 5.1. If it was less or equal to 5.1, then the chances of a landslide were relatively high. If the value was greater than 5.1, then there would be an 80% chance of a landslide, which was considered as a medium level warning. Likewise, if the SLP was less than or equal to twenty-six, then the data were checked for Rainfall (RF) at another level, which was also a highly contributing variable. If the value of the RF was less than one, which is 0–10 mm, then the chance of a landslide was '1', which was low, while if the value was greater than one, the data were checked for DTRD. If the DTRD value was less than or equal to 18.32, then the chance of a landslide was '2', which was a mid-level warning. If the value of DTRD was greater than 18.32, then there was a nearly 30% chance of a level 1 (Low) warning and a 70% chance of a level 2 (Mid) warning. The model was composed of five terminal nodes (response nodes), seven input variables, and a single response variable (LC) for the prediction of landslides. The overall accuracy of the model was calculated using a confusion matrix, which provided a holistic view of the model. The model showed an overall accuracy of 95.7% for the testing data and 98.3% for the training data. So we can say that this model is suitable for the classification of landslide chance occurrences based on various essential and highly significant factors (variables).

3.2.3. Adaptive Neuro-Fuzzy Inference System (ANFIS)

An Adaptive Neuro-Fuzzy Inference System (ANFIS) is the hybrid of two intelligent technologies, Fuzzy logic and Neural Networks [53]. Fuzzy logic is a Boolean logic extension based on Lotfi Zadeh's mathematical theory of fuzzy sets, which is a generalization of classical set theory [54]. Fuzzy logic provides an advantageous flexibility of reasoning by allowing inaccuracies and inconsistencies to be taken into account by introducing the notion of degree in the verification of a condition, thus allowing a requirement to be in a state other than true or false. The best thing about fuzzy logic is that it can provide a range of outputs that we can use to determine the likelihood of landslides. A fuzzy inference system consists of three parts, input (converts the crisp data into fuzzy data), engine (containing rules and membership function), and output (generating a de-fuzzified output).

The Neural Network is used to forecast future values on the basis of the historical data but does not have the ability of knowledge representation; so, the combination of both fuzzy and neural networks provides 'learning' as well as 'knowledge representation ability'. ANFIS is based on the 'Sugeno fuzzy mode', where a rule 'R' can be represented as:

Rn: IF μAi (x) AND μBi (y) THEN f = pn x + qny +rn,

where "n" = the total number of rules

Ai and Bi are the 'number of membership functions represented by' in the antecedent part of the rule 'R', and pn, qn, and rn are the linear variables of the subsequent part of the 'nt' rule.

ANFIS has five layers: one input layer, three hidden layers, and a single output layer, excluding an input layer (layer 0) [54]. The inputs are fuzzified at the first layer, where each node uses a 'trimf" function to evaluate a membership value for a linguistic term. The 'trimf' membership function was used for the input variables, since it showed a lower training and testing error than the other membership functions. The second layer multiplies the output from the first layer with a single factor, which performs min. (AND) operation. The firing strength of the rule is perceived by multiplying the membership values, which are denoted as μA_i (v_0) and μB_i (v_1), where a variable v_0 has a linguistic value of A_i and v_1 with B_i as a linguistic value in the antecedent part of Rule i, estimated using (Equation (2)). The third layer with'p' nodes normalizes the output of the second layer and generates the output as normalized firing strengths, which are calculated by dividing the strength of each node's node rule firing strength by the total strength of all firing rules, shown as Equation (3). The fourth layer obtains the normalized firing strength as the input and generates the first-order polynomial as the output. In this layer, every node calculates a linear function where the multilayer feed-forward mechanism of the neural network is used to adjust the function coefficients, shown as Equation (4). The fifth layer of the ANFIS adds every incoming signal and provides the final output evaluated using (Equation (5)).

$$\mathrm{p_i} = \mu \mathrm{A_i}(\mathrm{v_0}) \times \mu \mathrm{B_i}(\mathrm{v_1}), \quad (2)$$

where $\mu A_i(v_0)$ and $\mu B_i(v_1)$ are the membership values, A_i is the linguistic value of v_0, and B_i is the linguistic value of v_1.

$$\overline{\mathrm{p_i}} = \frac{p_i}{\sum_{J=1}^{R} \mathrm{pj}}, \quad (3)$$

where p_i is the firing strength of the ith rule computed in second layer.

$$\overline{\mathrm{p}}\mathrm{f_i} = \overline{\mathrm{p_i}}(\mathrm{m_0 v_0} + \mathrm{m_1 v_1} + \mathrm{m_2}), \quad (4)$$

where m_i's are the parameters, i = n + 1, while "n" is the number of inputs at layer 0.

$$\sum_i \overline{\mathrm{p}}\mathrm{f_i} = \frac{\sum_i \mathrm{p_i}\,\mathrm{f_i}}{\sum_i \mathrm{p_i}}, \quad (5)$$

where $\overline{p}f_i$ is the output of node 'i', while the summation of the rule consequents is the final output of the system.

The ANFIS simulations were carried out using ANFIS and the Fuzzy Logic toolbox of MATLAB 7.0. The data were divided using the 70% training and 30% testing split method. The FIS (Fuzzy Inference System) generated using the grid partitioning technique was used to tune the system parameters using the input and output training data. The training algorithm used the combination of both the backpropagation gradient descent as well as the least square method to model the training data. The 'Trimf' membership function with three membership functions for each variable was used to train the model, while the epoch number was kept constant at 50.

The model performance was evaluated using the root mean square error (RMSE) and the mean absolute error (MAE). The RMSE is the standard deviation of the prediction errors (residuals) [55]. The term "residuals" refers to the distance between the data points and the regression line. The RMSE is a measure of how the residuals are distributed. In other words, it indicates how closely the data are clustered along the line of best fit. The RMSE measures the average squared difference between the predicted and actual value [55]. The lower the RMSE value, the better the results. The RMSE is evaluated using Equation (6). The model performance was also analysed using the MAE shown in Equation (7), where x_k and z_k denote the network output and measure value from the kth element, respectively.

$$\text{RMSE} = \sqrt{\frac{1}{N} \times \sum_{K=1}^{N} (tk - yk)^2} \tag{6}$$

$$\text{MAE} = \frac{1}{N} \times \sum_{K=1}^{N} |x_k - z_k| \tag{7}$$

The performance evaluation of the ANFIS model showed a very low training error RMSE = 0.000299 and MAE = 0.00076. The model can be considered as a best fit prediction model with a high coefficient of determination.

3.2.4. Random Forest (RF)

A supervised learning technique based on a principle of ensemble learning contains 'n' number of decision trees on different subsets of the given dataset, which increases the predictive accuracy of the dataset [56]. Based on the output of each tree and the majority prediction votes, it predicts the final output. The decision tree can also be used for various machine learning applications, but the biggest drawback of the decision tree is the overfitting of training data [57]. Overfitting occurs when the trees are grown deeply to learn highly irregular patterns in the data. Random forest overcomes this limitation through the creation of multiple trees on various subspace areas at the cost of significantly reduced bias [58]. There are many other benefits to using RF approaches, for example, outliers or missing data can be ignored, data transformation and rescaling are not essential, and RF can handle both categorical and numerical data [59]. The RF model was developed using the 'random forest package' in the RStudio environment.

The random forest can be considered one of the best machine learning algorithms for its deep learning, classification, and prediction capabilities. The different number of trees and variables tried at each split are used to find the best combination for the superlative category and precise prediction outputs. The out-of-bag (OOB) error is used as a decision-making factor for the best combination of trees and variables at each split. Table 2 denotes in the first column the number of trees used in the random forest. The second column shows the number of variables tried at each split, and the third column denotes the out-of-bag (OOB) error.

As observed in Table 2, the rate of error decreased with the increase in the number of trees in the forest. The best combination showing a low OOB was observed to be with fifty-five trees trying two variables at each split. The confusion matrix of the model is shown in Table 3.

Table 2. The number of trees used in the random forest algorithm and the corresponding out-of-bag errors.

Number of Trees (ntree)	Number of Variables Tried at Each Split (mtry)	Out-of-Bag (OOB) Error
20	2	0.0276
28	4	0.0259
35	2	0.0198
44	4	0.0192
48	2	0.0138
50	3	0.0127
55	2	0

Table 3. Confusion matrix for the random forest algorithm for the LEWS.

Classes	1	2	3	Class Error
1	72	0	0	0
2	0	53	0	0
3	0	0	36	0

The confusion matrix evaluated for the model showed 100% accuracy, which we can consider as the best model for predicting landslide type problems. The experiments were carried out using two approaches known as hold out and cross-validation. In holdout, the data were portioned into two partitions (independent data sets). Here, 75% of the data was used to train the model, and the remaining 25% was used to test the model for accuracy. The cross-validation approach was used to find the best model and the best accuracy among the various models and methods utilized for future prediction. The default RF model was tuned using the "tuneRF" function in R-Programming to decrease the model's error rate, which was initially around 0.276 at ntree = 20 and mtry = 2 and dropped to zero at ntree = 55 and mtry = 2. The OOB error visualization is shown in Figure 7.

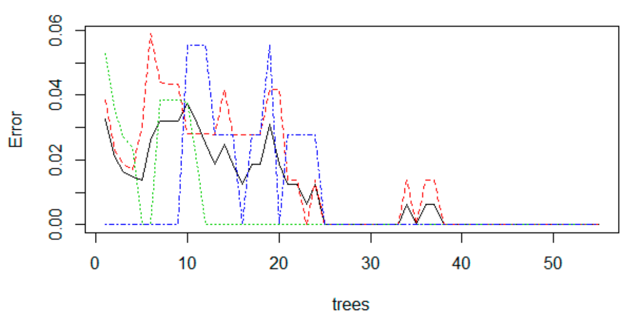

Figure 7. The random forest algorithm used in LEWS. The black line represents the out-of-bag error. The red, green, and blue lines represent the uncertainties in predicting each class (1 Low, 2 Medium, and 3 High, respectively).

The above figure shows how the OOB error decreased with the increase in the number of trees in the model. The model offered a high error rate between zero and twenty-five trees, which decreased from twenty-five to thirty-three and increased again from thirty-three to thirty-seven. After thirty-seven, the error dropped to zero and became constant.

Accuracy assessment is a crucial aspect of defining the quality of LULC maps. We collected several sample reference points from high-resolution Google Earth historical imagery and compared that with the mapped LULC each year. We performed stratified random sampling to collect the reference points. Based on the derived confusion matrices, the overall accuracy of the LULC classification of 2020, 2011, and 2000 was 96.32%, 94.12%, and 92.65%, respectively. The various other accuracy indices are shown in Table 4.

Table 4. Comparative accuracy assessment of the four different ML algorithms used in this study.

S No.	Model	ROC-AUC	RMSE	MAE	Sensitivity (TPR)	Specificity (TNR)	Accuracy
1.	MLR	0.973	0.0757	0.0377	-	-	98.27%
2.	ANFIS	0.997	0.000299	0.000076	-	-	99.80%
3.	DT	0.95	0.0949	0.0552	0.94	0.96	95.70%
4.	RF	1	0.0684	0.0186	1	1	99.50%

4. Results and Discussion

In this study, four machine learning models were used to predict landslides using both internal (geological and morphological) and external responsible (triggering) factors. The use of the two new significant responsible triggering factors (LST and BUA) resulted in improved model efficiency compared to when either one or both of these factors were not considered.

4.1. Establishing the Best Model for a Landslide Early Warning System (LEWS)

4.1.1. Multiple Linear Regression (MLR)

In the Multiple Linear Regression (MLR) model, the newly incorporated parameters were found to be highly significant and contributed to the overall model, as shown in Table 4 above. The models were evaluated using various tests, e.g., AUC, RMSE, confusion matrix, sensitivity, specificity, and mean absolute error. These showed the overall testing statistics and accuracy of the various machine learning models used to predict landslides. Figure 8 shows the algorithm flowchart used to perform the landslide chance estimation using the MLR model. At the end of the model run (stop), the results were generated.

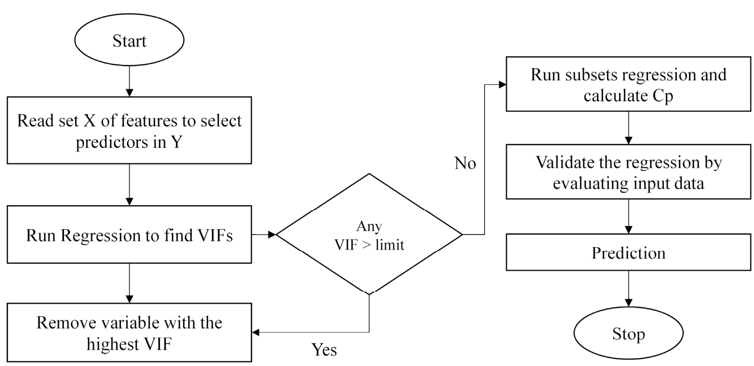

Figure 8. Algorithm flowchart of using MLR for modelling the landslide chances.

The prediction precision of the model was calculated by finding the difference between the predicted and observed data values. Using the function 'head (pred), head (testing)' in RStudio, the difference between the two values was evaluated by generating head (top) values of both the predicted and observed values. Both were found to be highly identical with very little difference. Further, the accuracy of the MLR model was improved from 95.79% to 98.27% by including the new variables in the model (Table 5).

Table 5. Significance of the variables used in the MLR algorithm.

	Estimate	Std. Error	t Value	Pr(>|t|)
(Intercept)	-4.483×10^{0}	1.301×10^{0}	-3.445	7.39×10^{-4} ***
RF	1.424×10^{-1}	2.509×10^{-2}	5.675	6.89×10^{-8} ***
LST	1.660×10^{-2}	4.107×10^{-3}	4.042	8.40×10^{-5} ***
SM	2.848×10^{-3}	9.985×10^{-4}	2.852	4.95×10^{-3} **
SLP	9.355×10^{-3}	1.539×10^{-3}	6.080	9.43×10^{-9} ***
DTRD	-8.189×10^{-3}	1.565×10^{-3}	-5.232	5.51×10^{-8} ***
DTR	-9.605×10^{-4}	2.592×10^{-4}	-3.706	2.95×10^{-4} ***
BUA	3.458×10^{-6}	1.034×10^{-6}	3.343	1.04×10^{-3} **

*** $p < 0.001$, ** $0.001 < p < 0.01$.

The predicted vs. observed data values are shown in Tables 6 and 7, respectively, while the graph in Figure 9a shows the predicted and observed data values graphically, which were highly identical and similar. Figure 9b, shows the high R^2 between the modelled and predicted landslide chances using the MLR model.

Table 6. Modelled values for landslide chances using MLR.

Predicted Values for Landslide Chances					
5	14	16	26	28	29
3.201248	1.029772	2.706106	1.064384	1.334708	1.910363

Table 7. Testing data values used as observational datasets for Landslide chances.

Observed (Testing) Data Values								
	RF	LST	SM	SLP	DTRD	DTR	BUA	LC
5	3	302.9989	312.9988	48	3.4	32.9	57884.84	3
14	1	296.7417	297.4413	14	27.0	289.4	28.40	1
16	4	301.0857	325.2137	28	3.6	87.5	54787.99	3
26	1	293.8275	299.4258	14	37.9	216.8	37.98	1
28	1	295.4806	296.5028	15	4.7	289.0	722.50	1
29	2	299.2426	299.1834	17	15.4	132.5	23676.47	2

RF, Rainfall LST, Land surface temperature SM, Soil moisture DTRD, Distance to road DTR, Distance to river BUA, Built-up area LC, Landslide chances.

As the method of experimentation, the model was tested by making some example predictions based on the different input data values provided to the model. The model predicted landslide chances as the upper limit, lower limit, and fit as shown in Table 8. Thus, the predictions generated by the MLR model were reliable.

Table 8. The modelled landslide chances as the upper limit, lower limit, and fit.

Prediction Results		
(1) predict(model, data.frame(RF = 3, LST = 300, SM = 340, SLP = 55, DTRD = 5, DTR = 20, BUA = 60776.22), interval = 'confidence')		
fit	lwr	upr
3.237494	3.170889	3.304098
(2) predict(model, data.frame(RF = 4, LST = 300, SM = 340, SLP = 55, DTRD = 5, DTR = 20, BUA = 60776.22), interval = 'confidence')		
fit	lwr	upr
3.379866	3.312526	3.447207
(3) predict(model, data.frame(RF = 2, LST= 296, SM = 300, SLP = 30, DTRD = 20, DTR = 140, BUA = 30005.22), interval = 'confidence')		
fit	lwr	upr
1.991868	1.943492	2.040245
(4) predict(model, data.frame(RF = 1, LST = 280, SM = 279, SLP = 6, DTRD = 45, DTR = 298, BUA = 100), interval = 'confidence')		
fit	lwr	upr
0.5047875	0.3681545	0.6414206
(5) predict(model, data.frame(RF = 2, LST = 298, SM = 280, SLP = 14, DTRD = 45, DTR = 298, BUA = 500), interval = 'confidence')		
fit	lwr	upr
1.029537	0.9467069	1.112368

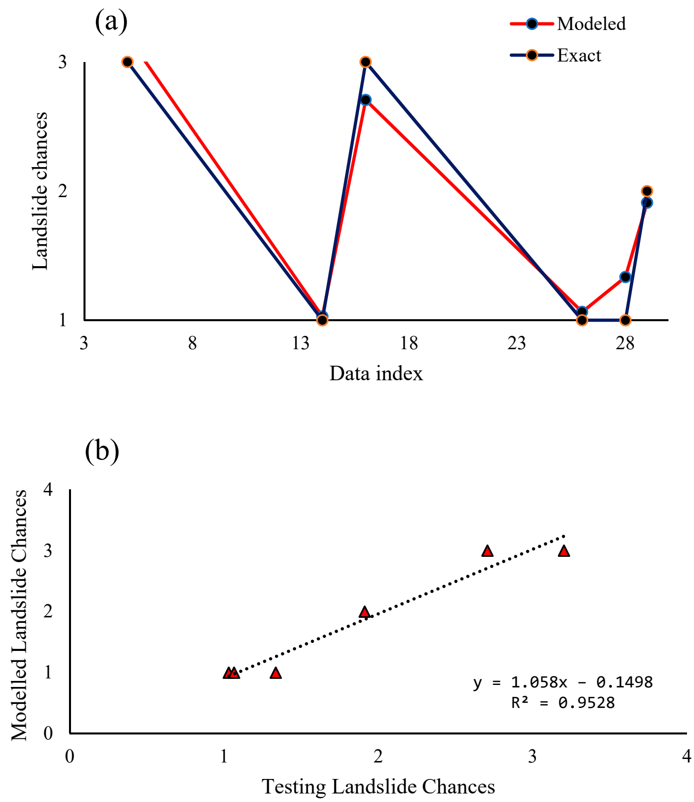

Figure 9. (**a**) Graph showing the predicted vs observed landslide chances (LC) using the MLR model against the model index values. (**b**) Predicted vs observed values for LC (1 *Low*, 2 *Medium*, and 3 *High*).

4.1.2. Decision Tree

The Decision Tree Model classified the testing data into various classification branches, which help to predict the result easily and precisely [60]. The model comprised five response nodes, seven input variables, and a single response variable (LC). A confusion matrix that provided a holistic view of the model was generated to calculate the model's overall accuracy. The model showed an accuracy of 95.7% for the testing data and 98.3% for the training data. The confusion matrix for both the training and testing data is shown in Tables 9 and 10, respectively. Figure 10 shows the conceptual algorithm flowchart of this model.

Table 9. Confusion matrix for the decision tree algorithm used in assessing the best algorithm for the LEWS (Training data).

		Actual	
Predicted	1	2	3
1	71	0	0
2	2	59	0
3	0	1	40

Table 10. Confusion matrix for decision tree algorithm used in assessing the best algorithm for the LEWS (Testing data).

		Actual	
Predicted	1	2	3
1	19	0	0
2	0	17	0
3	0	2	9

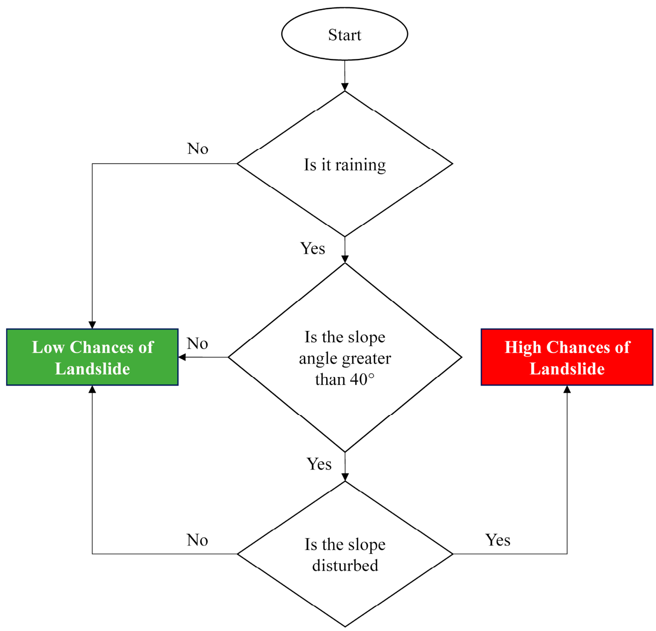

Figure 10. Conceptual algorithm flowchart of the decision tree algorithm for modelling the landslide chances.

The accuracy of the training data was calculated using Equation (8)

$$\text{Accuracy} = \frac{\text{TN} + \text{TP}}{\text{TP} + \text{FP} + \text{TN} + \text{FN (Total elements)}} \tag{8}$$

$$\text{Accuracy} = \frac{171}{174} = 0.9828$$

Likewise, the accuracy of the testing data was evaluated as:

$$\text{Accuracy} = \frac{45}{47} = 0.957$$

Therefore, the training data showed 98.3% accuracy, while the testing data showed 95.5% accuracy. The sensitivity and specificity were also calculated, as shown in Table 4, to find the significance and accuracy of the model.

The sensitivity or true positive rate (TPR) was calculated using Equation (9).

$$\text{TPR} = \frac{\text{TP}}{(\text{TP} + \text{FN})}, \tag{9}$$

where

TP = Number of True Positives;
FN = Number of False Negatives.

The specificity or the true negative rate (TNR) was calculated using Equation (10).

$$\text{TNR} = \frac{\text{TN}}{\text{TN} + \text{FP}}, \tag{10}$$

where

TN = Number of True Negatives;
FP = Number of False Positives.

4.1.3. Adaptive Neuro-Fuzzy Inference System (ANFIS)

The Adaptive Neuro-Fuzzy Inference System (ANFIS), a novel hybrid prediction algorithm blended with the learning abilities of neural network and transparent linguistic representation of the Fuzzy system, was used to generate a range of prediction responses to determine the degree of warnings for landslides that resolved the issue of the binary type of prediction classification used in various earlier studies. ANFIS is a hybrid intelligent system where both a neural network and a Fuzzy Inference System (FIS) are combined for better outcomes. The model followed a holdout data partitioning approach with 75% training and 25% test data for better predictions. The cross-validation technique was used to find the best model based on the prediction accuracy, execution time, and membership function. The best membership function was determined by using all membership functions. Table 11 shows the results from the ANFIS model. Figure 11 shows the algorithm flowchart used to perform the landslide chances estimation using the ANFIS. As can be seen from the flowchart, the testing was performed on the optimum variables once the training was finished during the early stages of the model run.

Table 11. Results from the ANFIS model.

Model	Epochs	Membership Function	Optimization Technique	Training Error (RMSE)	Avg. Testing Error
1	50	trapmf	Hybrid	0.084455	0.000450
2	50	gbellmf	Back Propagation	0.077573	0.000340
3	50	trimf	Hybrid	0.048609	0.000299
4	50	gaussmf	Hybrid	0.062222	0.000330
5	50	gauss2mf	Back Propagation	0.83243	0.000547
6	50	primf	Hybrid	0.59912	0.000646
7	50	dsigmf	Hybrid	0.16322	0.000402
8	50	psigmf	Back Propagation	0.16322	0.000402

All the ANFIS simulations were conducted using the ANFIS, Fuzzy Logic toolbox of MATLAB v. 7.0. The ANFIS model was tested by running the model in the MATLAB environment. An example prediction was generated using the model. The prediction generated was found to be highly significant and accurate. The model showed a minimal training error RMSE = 0.000299 and an average testing error of 0.048609, which is very low; so, the model can be considered a best-fit model for landslide predictions. The MATLAB code used for the ANFIS model execution in Fuzzy Logic toolbox environment was as follows:

Details of the ANFIS model.
Number of nodes: 4426
Number of linear parameters = 2187
Membership function type = Trimf

Number of membership functions = 3
Total number of parameters = 2250
Number of nonlinear parameters = 63
Number of fuzzy rules = 2187
Number of training data pairs = 158
Model Execution.
g= readfis ('T335.fis');
r = input ('RF (Rainfall in mm (1-4)) =');
a = input ('LST (Land Surface Temperature (284-306)) =');
b = input ('SM (Soil Moisture (283-305)) =');
c = input ('SLP (Slope (6-66)) =');
d = input ('DTRD (Distance to Road (1-45)) =');
e = input ('DTR (Distance to River (10-298)) =');
f = input ('BUA (Built-up area near Prone Site (1-29965)) =');
g = evalfis ([r a b c d e f], g);
disp (['Chances of Landslide:', num2str(h)]);
%h = output ('Chances of Landslide is:');
%xlswrite ('RPredict',h);
Response and output result of the model.
Input Variables and Input Values
RF (Rainfall in mm (1-4)) = 2
LST (Land Surface Temperature (284-306)) =290
SM (Soil Moisture (283-305)) =292
SLP (Slope (6-66)) = 14
DTRD (Distance to Road (1-45)) = 41
DTR (Distance to River (10-298)) = 290
BUA (Built-up area near Prone Site (1-29965)) = 500
Result: Chances of Landslide: 0.99562

The model generated an output 'Result' as Chances of Landslides = 0.99562, nearly equal to '1'. Therefore, it meant that the model generated a 'Low' level warning for the input data provided. The warning output generated by the model was found to be highly accurate with a low RMSE and misclassification.

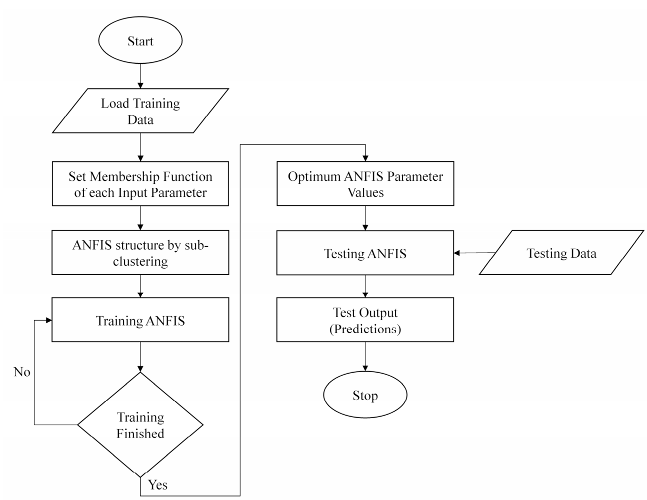

Figure 11. Algorithm flowchart of the ANFIS model used in the present study to model the landslide chances.

4.1.4. Random Forest (RF)

Random Forest, a machine learning algorithm known for its deep learning, classification, and prediction capabilities, was used to classify and predict the chances of landslides. Training data were provided as an input to the model, which classified it into various classes based on the variable importance and its significance to the overall model. The model tried different numbers of trees and variables at each split to find the best combination for superlative classification and precise predictions. Figure 12 shows the algorithm flowchart used to perform the landslide chances estimation using the random forest model; it can be seen that this model uses extensive processes and loops for calculating the training dataset. This is the reason for its very high precision and accuracy in any machine learning-based land system process modelling.

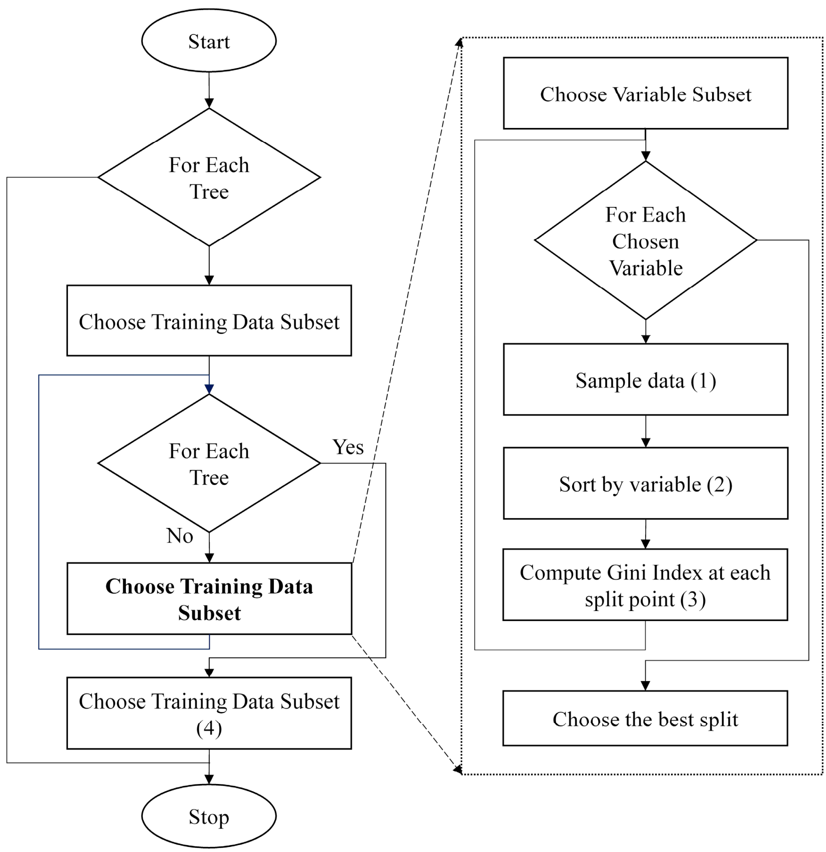

Figure 12. Algorithm flowchart of the RF model used in the present study to model the landslide chances. Choosing training data is the most extensive and rigorous process in this model.

Model Details
Number of trees = 55
OOB estimate of error rate = 0%
ROC Area = 1 (100%)
Mean absolute error = 0.0186
Relative absolute error = 4.2596%
No. of variables tried at each split = 2

Correctly Classified Instances = 66 (100%)
Root mean squared error = 0.0684
Incorrectly Classified Instances = 0 (0%)
Root relative squared error = 14.5608%

The model showed nearly about 99–100% accuracy, with 100% correctly classified instances. The model's error rate was initially around 0.276 at ntree = 20 and mtry =2, which dropped to zero at ntree = 55 and mtry = 2 as shown in (Figure 6). The prediction accuracy of the model was analysed by comparing and calculating the difference between the predicted and observed data (testing data) values, which was as follows:

1 2 3 1 1 3 (Head values of predicted data set: (head (p1))

1 2 3 1 1 3 (Head values of testing data set.: head(test$LC))

The model showed approx. 100% accuracy when matched with the data that the particular tree had not seen (testing data). So, the model can be considered as a best-fit model for the classification and prediction of landslides.

4.2. Landslide Early Warning System (LEWS) and Land System Processes in the Rugged Himalayan Mountains

We performed multiple experiments that showed that ANFIS and RF outperformed the other proposed methods for establishing a landslide early warning system for the stretch of national highway between Chanderkote and Jawahar tunnel in J and K, India. All the independent variables used in both models were found to be significant. At the same time, the newly added variables LST and BUA (Built-up Area near the prone site) were also highly influential in increasing the accuracy of the model results, which until now have not been used to predict the chances of landslides. The evaluated P-values (significance of variables) showed that both variables were highly significant and contributed to the models. The overall prediction accuracy improved from 95% to 99% in ANFIS and the Random Forest algorithm. From these results, it is proposed that along the studied stretch of the national highway, at all vulnerable sites, sensors that provide information about the real-time ambient soil moisture and rainfall measurements should be installed. This can be used in the proposed LEWS system to provide real-time information about the chances of occurrences of landslide events using other satellite-derived variables.

The main factor contributing to the high landslides in the study area is the slope. In other words, surface topography is one such landscape characteristic that helps understand why some places are comparatively more vulnerable to landslides than others [61–64]. The topography has a significant effect on landslide kinematics [65]. The region's topography includes incised engraved valleys and rugged mountains with narrow gorges and very steep slopes having no or very little vegetation over the slopes [66]. To understand the higher vulnerability of the area to landslides, we created a buffer of 5 km around the studied stretch of the national highway (Figure 13). It can be observed that within this area, the elevation ranges from 605 m to 3666 m, which ascribes the study area with a higher relief and slope (Figure 13a). The other manifestation of the elevation is slope and contours, helping to visualize surface topography more intuitively. The slope angle formed one of the essential inputs to all the models. As shown in Figure 13b, the percent slope rise in the study area within the 5 km radius is exceptionally high, ranging from 0.00 to 160.28. Such areas with extremely high slope rises are typical of Himalayan landscapes. It provides the landslides with the required gravitational force to occur [67]. According to many studies, it is a key factor causing slope instabilities [68,69]. The slope angle governs the retention of moisture and vegetation on the slopes, affecting its stability and soil strength. Slope angle affects the amount of rainfall falling on the slope due to the impact of wind on the slope, diverse slope aspects, and curvature [70].

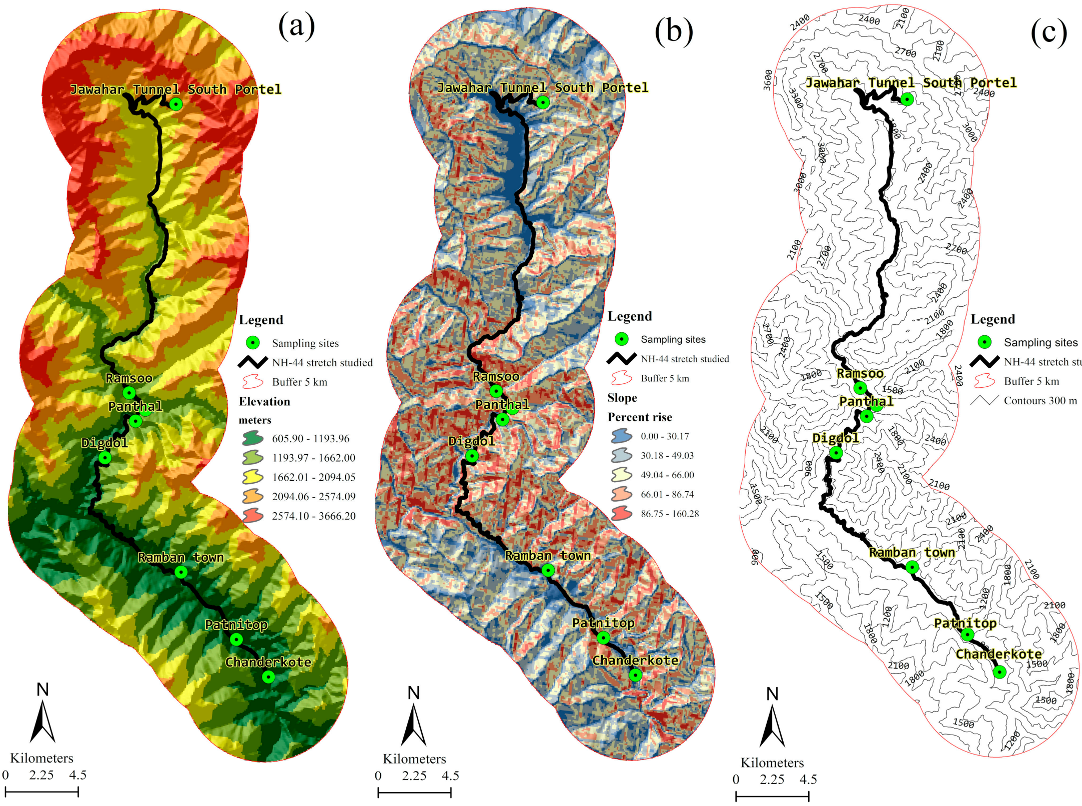

Figure 13. (**a**) Elevation map, (**b**) slope map, and (**c**) contour map of the study area.

Various studies in the Himalayan regions have carried out landslide assessments. Studies have evaluated the impact of landslides by assessing their velocity, damaged area, and the distance of their runouts. Guo et al., (2022) carried out an in-depth analysis of the causes of the landslides and determined the deposit patterns using finite difference and numerical methods. Similar to the present study, this study evaluated the accuracy of the model using three new variables, friction coefficient, critical velocity, and steady friction coefficient. Studies have concluded that landslides are governed by regional geomorphic, geological, and climatic conditions, and thus any assessment requires an evaluation of all the contributing factors [71]. In addition, erratic rainfall is also one of the important triggering factors.

The slopes along NH 44 national highway have suffered huge deformations due to heavy vehicular traffic, road widening, construction along the highway, and tectonic movements [68–70]. The area from 'Nachlana' to 'Seri' is highly prone to landslides, with many active landslides present in the area. Most of the landslides on the National Highway were reported and identified in the same region. Therefore, this area can be considered a highly prone and vulnerable area to landslides. The landslide occurrences resulting from various other parameters in this area are strongly increased due to heavy traffic on this highway. Studies have shown how traffic intensity affects the frequency of landslide occurrence on this highway [66,68,69]. The vibrations due to heavy transport, which includes the most significant proportion of heavy motor vehicles, is possibly the force influencing the mass movements in this area. Road construction along the mountainous region is often simultaneously accompanied by mining, and the slopes become unstable and result in landslides after a spell of rainfall. Moreover, the consequences become disastrous when the conditions are as on the NH 44 highway. Studies have been carried out that have evaluated the impact of rainfall on rock deformations. While assessing such a relationship, Li et al., (2022) concluded that the water content of the land mass movement has a direct relationship, and it is the result of rainfall variability that induces the failure of the soil interlayers and results in landslides. Such studies aimed to provide landslide prediction using real-time information about rainfall and soil moisture condition, similar to what has been achieved in the present study [72].

We have also shown the 300 m contours of the study area (Figure 13b). The contours of the study area range from 495 m to 4510 m, with very steep slopes that can highly influence the landslides and rockfalls over the area. Contour lines are important for landslide investigation and analysis because they allow us to investigate the overall topography of the landmass. In recent years, many studies have been carried out on the effect of topography on landslides. Different terrain mechanisms were explored with the help of various indoor model experiments [73–75], and the landslide masses' mechanical properties were explored with varying levels of moisture and terrain structures. All the parameters used in this study contributed to the landslides' occurrence. According to various studies, moisture (precipitation) and topographical properties play a significant role in triggering landslides [76–79]. The excessive moisture in the soil increases the pore pressure, which decreases the shear strength of the soil and leads to slope failure [78].

Based on the previous research [68], and the current analysis, the key factors responsible for landslides on the Jammu Srinagar National Highway assessed were intensive rainfall events, anthropogenic activities, slope morphology, heavy traffic, vegetation density, changes in ground and surface water, land surface temperature (LST), and ongoing climate change, which has exacerbated their frequency of occurrences [80–86]. Rainfall is a common factor triggering landslides. Intense or prolonged rainfall events decrease the shear strength and internal friction between the soil particles and cause the soil to slide downward, causing often fatal landslides [87,88]. There are also increases in the extreme precipitation events over the study area (Jammu and Kashmir), which have the potential to increase the frequency of natural hazards such as floods, landslides, snow avalanches, floods, GLOF, and LLOF [89,90]. Further, the soil profile on the slopes of this area is loose naturally; hence, a low intensive rainfall event is enough to trigger a landslide [68]. This is mainly because the mountain characteristics near the study area, which is dominated by weak metamorphic rocks such as lithosole, sedimentary rocks, and semi-consolidated to consolidated sandstones and siltstones, show active weathering processes and liquefaction properties during prolonged precipitation events (Siwalik Himalayan Belt) [91–95]. The weathering and liquefaction properties of the stones deposit a layer of clay and silt material on the slopes [96–99]. At the same time, the sandstones are transformed into small and fine-grained rock pieces and granules, which make slopes highly unstable and prone to failure [100]. Most of the land failures in the study area are covered with thick colluvium material, claystone, mudstone, and siltstone [68]. In contrast, others are covered with sedimentary rocks and sandstone granules, making these sites highly prone to rainfall-induced land failure [68]. All these factors make the region highly susceptible and prone to landslides [68,89,100–102].

5. Conclusions

This paper used field data, satellite remote sensing, and different machine learning methods to create a landslide early warning system for the selected stretch of the national highway NH 44 in Jammu and Kashmir. Four machine learning approaches were explored (Multiple Linear Regression, Decision Tree, Random Forest, and Adaptive Neuro-Fuzzy Inference System) to deduce the most accurate model for a LEWS for accurate landslide predictions. The proposed methods were validated and tested using various statistical and machine learning tests. Two new parameters were included (BUA and LST), which, so far, have not been used in any study; they were found to be highly significant and contributed to all the models' accuracy and prediction. The ANFIS and Random Forest models outperformed the others and showed a higher accuracy, a lower misclassification, and a lower mean square error. We are further including more field sites in the analysis to experiment with the critical values of the variable at many other vulnerable landslide sites on the national highway stretch. Including more locations in the evaluation will help the hazard managers use appropriate sensors at vulnerable locations to provide better early warnings. This study will help the region's decision makers and policy makers to manage the landslides with informed knowledge and insights to cope with the damage they cause every year.

Author Contributions: Conceptualization, M.F. (Mohsin Fayaz), S.A.K. and G.M.; methodology, M.F. (Mohsin Fayaz), S.A.K., G.M. and M.F. (Majid Farooq); software, M.F. (Mohsin Fayaz) and G.M.; validation, M.F. (Mohsin Fayaz), S.A.K. and G.M.; formal analysis, M.F. (Mohsin Fayaz), S.A.K., G.M. and M.F. (Majid Farooq); investigation M.F. (Mohsin Fayaz), S.A.K., G.M., S.K., S.K.S. and M.F. (Majid Fayaz); resources, P.K. and S.A.K.; data curation, M.F. (Majid Fayaz); writing—original draft preparation, M.F. (Mohsin Fayaz), G.M.; writing—review and editing, G.M. and P.K.; visualization, M.F. (Mohsin Fayaz), S.A.K. and G.M.; supervision, S.A.K. and P.K.; project administration, M.F. and N.S.; funding acquisition, P.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data available upon request to authors.

Acknowledgments: The authors are thankful to the three anonymous reviewers whose critical reviews have improved the quality of this manuscript. The author G.M. is thankful to the Department of Science and Technology, Government of India (DST-GoI) for providing the Fellowship under the Scheme for Young Scientists and Technology (SYST-SEED) [Grant no. SP/YO/2019/1362(G) & (C)]. We are also thankful to the Border Roads Organization (BRO) for providing every possible support during the fieldwork of this research. Further, we are also indebted to Divisional Commissioner (DC), Ramban for all the logistic support during the whole tenure of this research project.

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

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Assessment on the Urbanization Quality of China's Main Grain-Producing Areas under the SDGs

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Abstract: The Sustainable Development Goals (SDGs) adopted by the United Nations in 2015 guide the important direction of high-quality urbanization in China's main grain-producing areas (MGPAs), and improving the quality of urbanization is also crucial to achieve the SDGs. China's MGPAs not only undertake the task of promoting urbanization but also of ensuring food security. The establishment of an index system based on SDGs can more effectively measure the urbanization quality of MGPAs. For the specific targets of the SDGs, this study established two sets of multidimensional indicator systems, whether including the goals of food and agriculture, and tracked the progress toward improving urbanization quality of China's MGPAs, including 128 prefecture-level cities, during 2010–2018. We found that the comprehensive urbanization quality and the index of economic efficiency, urbanization level, and environmental quality showed an upward trend with significant regional differences and spatial agglomeration distributions, but the level of agricultural development and urban–rural co-ordination have declined in recent years; the ranking and distribution of urbanization quality, including agricultural development, varied significantly, and the number of cities belonging to the good co-ordination mode decreased as some cities changed to a lower level; and urbanization that does not sacrifice the agricultural capabilities of MGPAs could improve urbanization quality and implement the SDGs.

Keywords: sustainable development goals; urbanization quality; agricultural development; main grain-producing areas; China

Citation: Geng, F.; Zhang, J.; Miao, C.; Shang, W.; Yuan, L. Assessment on the Urbanization Quality of China's Main Grain-Producing Areas under the SDGs. *Land* **2022**, *11*, 1163. https://doi.org/10.3390/land11081163

Academic Editors: Carmen Delgado Viñas and María L. Gómez-Moreno

Received: 21 June 2022
Accepted: 23 July 2022
Published: 27 July 2022

1. Introduction

The contribution of urbanization to land-use change has become an important sustainability issue [1], especially for China, where rapid urbanization has exacerbated the conflict between agricultural and urban land. Urbanization has developed rapidly in the 20th and 21st centuries and has been regarded as an important development strategy [2]. With increasing global urbanization, the Earth is gradually becoming an urban planet [3,4]. China's urbanization has shown unprecedented speed and scale in recent decades, and has become an important force to promote global sustainable development. However, urban land expansion modifies habitats, biogeochemistry, hydrology, land cover, and surface energy balance [5]. More than 60% of the world's irrigated croplands are located near urban areas [6], but main grain-producing areas (MGPAs) are also being eroded by rapid urbanization [7,8], and this is demonstrated in numerous cases in China, the USA, Egypt, Turkey, India, and other countries [1]. The Food and Agriculture Organization of the United Nations pointed out that the current global food crisis is further worsening [9]. Deciphering how to scientifically measure the urbanization quality of MGPAs and co-ordinate the relationship between food production and urbanization has become an urgent problem to be solved. SDGs have become the consensus of the international community and guide the direction of economic development in various countries [10]. The MGPAs' urbanization should follow the SDGs and focus on improving the quality of urbanization.

Urbanization embodies the process of population and land use transfer from rural areas to cities and towns. It is also the transformation process and improvement of people's lifestyle, productivity level, and quality of life [11]. By the end of 2021, the urbanization rate of China's permanent population had reached 64.72% [12], of which the urbanization rate of Shanghai, Beijing, and Tianjin had exceeded 80%. However, at the same time, the urban–rural imbalance in economic and social development has become increasingly prominent, and food security is the most unstable and vulnerable problem [13].

Most scholars agree that agricultural development is inversely related to industrialization and urbanization [14]. Especially for MGPAs, because of the constraints on available cultivated land, it seems that there is always a contradiction between ensuring national food security and promoting urbanization.

Knowing how to measure the development level of urbanization has always been the first problem in the stage of rapid urbanization [15]. Previous studies were mostly based on single or comprehensive indicators such as population, economy, and land. In recent years, the fusion of multisource data such as nighttime lighting and land use have also been widely used [15,16]. However, most studies rarely use agriculture and food security as the indicator system; only MGPAs consider agriculture as one of the indicators of the urbanization development [13,17].

In China, the most important way to solve the contradiction between urbanization and cultivated land protection is to implement the strategy of major function zoning, which is defined by an area's specific, core function based on its environment, social and economic strength, and development potential [18,19]. It is mainly divided into four types of optimized, prioritized, restricted, and prohibited zones [20]. The MGPAs belong to the restricted zones, and undertake the dual tasks of promoting urbanization and ensuring food security, mainly including Heilongjiang, Henan, Shandong, Sichuan, Jiangsu, Hebei, Jilin, Anhui, Hunan, Hubei, Inner Mongolia, Jiangxi, and Liaoning [21].

Although China has controlled MGPAs through spatial planning, there are still many problems under rapid urbanization. First, the phenomenon of nonagricultural utilization of cultivated land such as occupying cultivated land for constructing high-speed railways, highways and roads, digging lakes and canals, and occupying permanent basic farmland for greening and afforestation has intensified [22], resulting in a sharp decrease in arable land and weakening the food-production capacity. Second, the development of urbanization has attracted young and middle-aged labor from rural areas to flow into cities on a large scale, resulting in widespread abandonment of farmland in rural areas and the conversion of double-cropping rice to single-cropping rice, which has a serious negative impact on food production [23–26]. Third, urbanization also causes soil quality degradation and soil erosion [27], intensifying water competition in food production [28]. Fourth, most of China's MGPAs have long been in the embarrassing situation of "large grain province/county and financially poor province/county", and the phenomenon of "grain and wealth upside down" is serious [29], resulting in increasingly prominent contradictions between grain production and urbanization. Therefore, it is urgent to solve the problem of sustainable development of urbanization in China's MGPAs.

The United Nations proposed 17 Sustainable Development Goals (no poverty, zero hunger, good health and well-being, clean water and sanitation, affordable and clean energy, decent work and economic growth, industry, innovation and infrastructure, reduced inequalities, and sustainable cities and communities, etc.) in 2015 and most countries had committed to solve their toughest sustainable development challenges by 2030 [30,31]. Since then, many studies built a theoretical framework based on the SDGs and established an index system to finally measure the level of sustainable development, but the index system and measurement method varied with research needs [10,30]. However, we find that the SDGs cover a lot of content and are very comprehensive, but lack goal orientation, which makes it difficult to apply them to other research issues. Some scholars have gradually recognized this problem and began to clarify their own research questions, and then selected some indicators to establish a theoretical framework based on the SDGs [32]. Therefore, we believe that it is necessary to closely follow the research question itself and selectively apply the theoretical framework of the SDGs to make it more valuable.

SDGs are the best guidelines to high-quality urbanization, so urbanization is increasingly integrated with the SDGs [31,33]. To begin with, sustainable cities (Goal 11) put forward specific requirements for urbanization and are widely embedded in a high-quality urbanization measurement index system. Scholars not only emphasized the traditional three indicators of society, economy, and environment, but also further attention indicators such as urban resilience, health and well-being, and poverty eradication. Some studies analyzed the difficulties and evaluated the practice of specific cities in achieving Goal 11 [32,34–37]. Next, urbanization has played an important role in economic growth and poverty reduction, and is the main driving force and way to achieve the SDGs [38]. Eliminating urban diseases induced by urbanization is a common and sustainable development issue in the world during this period. In addition, the relationship between the different SDGs is also valued. Some studies have focused on the relationship between Goal 11 and other goals, such as the impact of poverty and urbanization on sustainable development [37], the challenges posed by urbanization to food security [39], and urban–rural linkages [36]. Meanwhile, other studies have also constructed evaluation systems that take into account various subgoals of the SDGs [40,41]. Finally, determining how to formulate urbanization policies according to the sustainable development goals has also become a research hotspot [42–44].

Existing research results are rich, but the following problems still exist. Firstly, most studies are only focused on Goal 11, which failed to fully reflect the high-quality development of urbanization. More attention should be paid to the other goals related to urbanization, and the evaluation indicators need to be further in line with the specific targets of the SDGs. Secondly, we should focus on the change trend of urbanization quality to examine its improvement degree and SDGs' realization progress. Thirdly, China's urbanization presents significant regional differences. It is necessary to consider the heterogeneity of urbanization background and process among different regions, and strengthen the research on different types of regions. More importantly, the research with regard to MGPAs has generally failed to combine urbanization quality with the SDGs, and also failed to consider the role of agricultural development in urbanization process [45,46]. SDGs provide a good multidimensional framework for exploring the high-quality urbanization of MGPAs without sacrificing agriculture and grain security. Therefore, MGPAs' urbanization should be oriented toward the SDGs. It is critical need to embed the specific targets of the SDGs in the process of improving urbanization quality.

Above all, this paper innovatively included the agricultural development in the discussion of MGPAs' urbanization quality, and established two sets of multidimensional indicator systems corresponding to sustainable cities (Goal 11), food security (Goal 2), and other related goals. We tracked MGPAs' progress toward improving urbanization quality during 2010–2018. This study is essential in regards to formulating urbanization policies and exploring sustainable urbanization modes, and also provides a reference for other developing countries.

2. Analysis Framework

SDGs provide clear guidelines for all countries to clarify their future development priorities according to resource conditions and development backgrounds [32]. This study combined the SDGs with the status and tasks of MGPAs to explore urbanization quality. We built an analysis framework, as depicted in Figure 1.

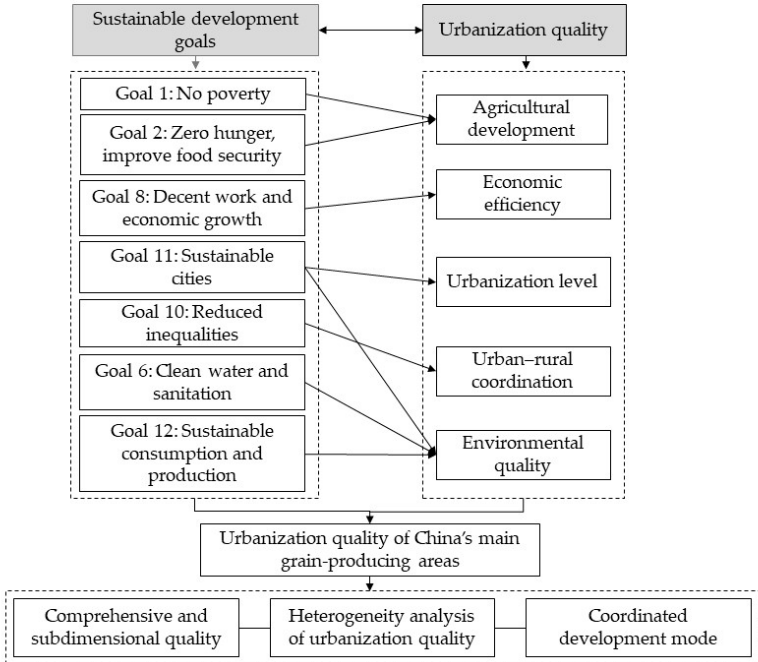

Figure 1. Analysis framework of the study.

(a) Construction of multidimensional evaluation indicator system. Among the 17 SDGs, the goals related to MGPAs' urbanization quality included Goals 1, 2, 6, 8, 10, 11, and 12. In line with these goals, we constructed the following indicator system for evaluating urbanization quality.

In the beginning, the sustainable development of agriculture and urbanization are effective ways to achieve Goal 1 (no poverty) and Goal 2 (zero hunger, improve food security) [47]. Agriculture provides important resource support for economic development, and is the foundation for ensuring national food security and social stability. The improvement of agricultural production capacity plays an important role in solving the problem of food and increasing farmers' income. At the same time, the continuous advancement of urbanization drives the aggregation and optimal allocation of resource elements, which is conducive to improving production efficiency and promoting the development of poverty-stricken areas [48]. MGPAs face the dual pressure of improving urbanization quality while increasing grain yield. Therefore, it is important to highlight the role of agricultural development in urbanization and introduce the constraint condition of agricultural development into the analysis framework.

Moreover, economic efficiency reflects the economic growth mode and operation quality, and is the internal driving force of urbanization and an important factor in decent work and economic growth (Goal 8) [49]. In this regard, the mode of economic development should be changed from an extensive one focused on rapid development to an intensive one focused on efficiency. In addition, the improvement of economic efficiency is conducive to sustainable economic growth and supports the further adjustment of the urbanization development mode.

Furthermore, sustainable cities (Goal 11) provide guidance for the assessment of urbanization level. Urbanization rate directly reflects the urbanization process and is an important indicator of urbanization level. Considering the characteristic of semiurbanization under China's dual household registration system, the urbanization level should consider the structure of urban population [50]. Therefore, we should also pay attention to the migrant agricultural population. It is necessary to promote their urban citizenship status and ensure the access to public services to achieve inclusive and sustainable development of urbanization.

Additionally, co-ordinated urban–rural development is an inherent requirement for high-quality urbanization, and also an important part of reducing inequality (Goal 10). Urban–rural co-ordination includes urban and rural politics, economy, ecological environment, population, culture, income and space, etc. [51]. The rural–urban relationship is the most important interdependent aspect in a region [52]. However, the current unequal spatial development mode focusing on urban development has caused significant gaps between urban and rural areas, and the interests of rural areas have been damaged to a certain extent. Thus, a good relationship between urban and rural areas should be established, and cities should give full play to the driving role in the regional development, so as to gradually narrow the urban–rural development gap and achieve a greater degree of equality.

Last but not least, a good environment is an important guarantee for high-quality urbanization, and Goal 6 (clean water and sanitation), Goal 11, and Goal 12 (sustainable consumption and production) set requirements for the improvement of environmental quality during urbanization. Production and construction inevitably have negative environmental effects. Among them, water pollution and air-quality degradation are particularly prominent [53,54]. Relevant measures, such as reducing pollutant discharge intensity and strengthening pollution control, should be actively implemented to improve environmental quality. Thus, we focused on the improvement process of water and air quality to analyze the environmental sustainability.

(b) Heterogeneity analysis of urbanization quality. Urbanization development has a high degree of spatial heterogeneity [31] because there are differences in resource endowments and development levels in different regions. Therefore, we focus on the temporal and spatial dynamics of urbanization quality at the provincial and municipal levels, and consider regional differences in comprehensive and subdimensional qualities. Clarifying the multiscale pattern of urbanization quality can help MGPAs to formulate targeted policies.

(c) The co-ordinated development model of urbanization. High-quality urbanization attaches great importance to the co-ordinated development among all the elements [55]. Accordingly, based on our measurement of urbanization quality, we further examined the co-ordinated development modes of urbanization quality.

3. Study Areas

China's MGPAs have significant agricultural production advantages and perform the important task of ensuring China's food security. Considering regional population density and the proportion of agricultural population, we select nine provinces (excluding Liaoning, Heilongjiang, Jilin, and Inner Mongolia) as research objects, including 128 cities (Table 1 and Figure 2).

Table 1. Comparison of the mean values of relevant indicators in different regions in 2018.

Region	Population Density (Person/sq. km)	Grain Output (1000 Tons)	Per Capita Share of Grain (kg/Person)
MGPAs	561	268	484
Densely populated agricultural areas	608	411	617
Nondensely populated agricultural areas	519	138	364

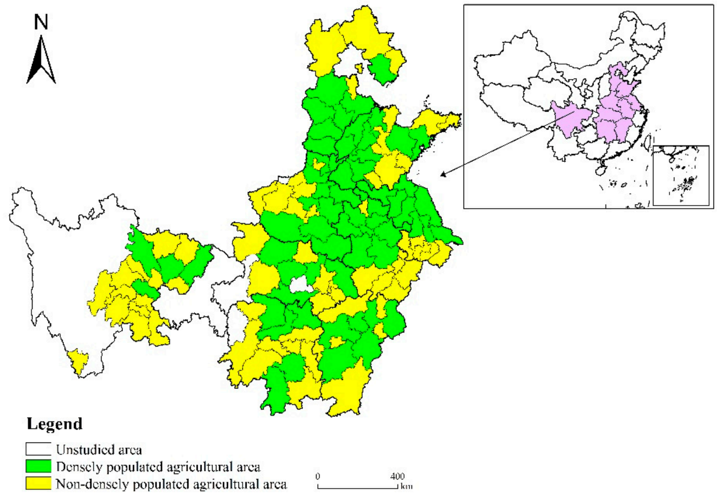

Figure 2. Locations of MGPAs including 128 prefecture-level cities in China.

In 2018, MGPAs had a population of 670 million people, accounting for 48% of China's total population (Table 1). The GDP and grain output accounted for 46% and 53% of China's total, respectively. The urbanization rate was 57.58%. It can be seen that the population, economy, and grain output of MGPAs account for relatively high proportions of the national totals, and urbanization is in a stage of accelerated development. Therefore, promoting high-quality urbanization without sacrificing agriculture has great practical significance for MGPAs.

To further analyze urbanization quality, we divide cities into two types. Specifically, we compare the average grain production of each city with the national average during 2010–2018, and employ the standard of 400 kg per capita as the criterion for whether food production reaches a well-off level [56]. Cities with both indicators higher than the baselines are classified as densely populated agricultural areas; other cities are classified as nondensely populated agricultural areas. Table 1 and Figure 2 show the division results and relevant indicators, respectively. Sixty-one cities belong to densely populated agricultural areas; these are mainly gathered in the central and northern plains of MGPAs. Sixty-seven cities belong to nondensely populated agricultural areas.

4. Materials and Methods

4.1. Construction of Multidimensional Evaluation Indicator System and Weight Settings

Considering the SDGs, data availability, and the goal of being scientific, systematic, and representative, we established evaluation indicators for each dimension and determined their weights based on the Delphi method.

We used the Delphi method in two stages. At the first stage, we invited 15 professors, associate professors, and postdoctoral fellows to determine the indicator system. They have high standards and rich research experience in China's MGPAs, urbanization, and regional development. Experts believe that the selection of indicators should be closely combined with the development characteristics of the study area to enhance the pertinence of indicators. First, we initially characterized the dimension of agricultural development in terms of per labor agricultural output value, per capita grain output, and the level of agricultural mechanization. Experts believed that this paper should focus on agricultural output, but agricultural mechanization represents the level of agricultural modernization to a greater extent. Thus, we finally eliminated the level of agricultural mechanization and kept the remaining two indicators. Second, data envelopment analysis (DEA) was used to measure economic efficiency, including scale efficiency and technical efficiency [57,58].

Employees, built-up area, and fixed-asset investment are the input indicators, and GDP and fiscal revenue are the output indicators. This dimension was more recognized by experts and had not been modified. Third, in the dimension of urbanization level, we initially only selected a single indicator of the proportion of urban population. However, experts believe that with the influx of a large number of people into cities, the degree of urbanization of the population is also an important issue in the process of urbanization in recent years. Therefore, we added the degree of civicization as one of the indicators. Fourth, we measured the urban–rural per capita income gap, per capita consumption gap, and per capita medical gap in terms of urban–rural overall planning. However, experts believe that the urban–rural per capita income gap and per capita consumption gap can largely reflect the urban–rural development gap. Although the urban–rural medical gap can reflect the gap in public resources between urban and rural areas to a certain extent, it is difficult to obtain data on the urban–rural medical gap in some cities, so this indicator is excluded. Fifth, in terms of environmental quality, we initially used PM2.5, sewage discharge, and comprehensive utilization rate of industrial solid waste to measure [49]. PM2.5 is one of the most important pollutants in air pollution in China, but it is rarely included in the existing evaluation system [59]. However, experts believe that the indicators should be comparable, and the total sewage discharge needs to be changed to sewage discharge intensity. At the same time, the dimension of environmental quality should reflect the pollution situation in the process of urbanization. In addition, due to the limitation of data, the comprehensive utilization rate of industrial solid waste is excluded, so we finally chose PM2.5 and sewage discharge intensity as indicators. Further, we also constructed two sets of indicator systems. One is a four-dimensional indicator system without the agricultural development dimension. The other is a five-dimensional indicator system that includes the agricultural development dimension. These were used to compare evaluation rankings before and after adding the agricultural development indicator and explore urbanization quality characteristics on the premise of not sacrificing agriculture. Tables 2 and 3 show the primary and secondary indicators.

Table 2. Four-dimensional evaluation indicator system and the weights of urbanization quality.

Primary Indicators	Weight	Secondary Indicators	Indicator Properties	Weight
Economic efficiency	0.25	Technical efficiency	Positive	0.15
		Scale efficiency	Positive	0.10
Urbanization level	0.25	Urbanization rate	Positive	0.15
		Citizenization	Positive	0.10
Urban–rural co-ordination	0.25	Urban–rural income gap	Negative	0.125
		Urban–rural consumption gap	Negative	0.125
Environmental quality	0.25	PM2.5	Negative	0.125
		Sewage discharge intensity	Negative	0.125

Table 3. Five-dimensional evaluation indicator system and the weights of urbanization quality.

Primary Indicators	Weight	Secondary Indicators	Indicator Properties	Weight
Agricultural development	0.12	Per labor agricultural output value	Positive	0.06
		Per capita grain output	Positive	0.06
Economic efficiency	0.22	Technical efficiency	Positive	0.132
		Scale efficiency	Positive	0.088
Urbanization level	0.22	Urbanization rate	Positive	0.132
		Citizenization	Positive	0.088
Urban–rural co-ordination	0.22	Urban–rural income gap	Negative	0.11
		Urban–rural consumption gap	Negative	0.11
Environmental quality	0.22	PM2.5	Negative	0.11
		Sewage discharge intensity	Negative	0.11

In the second stage, we held a symposium with 15 experts to determine the indicator weights. In the existing literature, objective weighting methods, such as the entropy method, are often used [60,61]. However, they relied too much on the statistical data of indicators, ignoring the importance of the indicators themselves in the research content. In contrast, indicator weights obtained on the basis of research area characteristics and experts' experience are more in line with the connotation of MGPAs' urbanization quality under the SDGs, and are conducive to the comparability among indicators. First, economic efficiency, urbanization level, urban–rural co-ordination, and environmental quality are of equal importance for improving urbanization quality of MGPAs, and these four indicators were given the same weight. In addition, agricultural development is the basis and a prerequisite for urbanization and is an important process accompanying urbanization. Thus, its weight was 0.12, which was relatively lower than the weights of other dimensions. Second, specifically for agricultural development, as core indicators reflecting agricultural output, per labor agricultural output value and per capita grain output are of the same weight. For economic efficiency, the improvement of urban economic efficiency is more influenced by technical efficiency. The weight of technical efficiency was slightly higher than scale efficiency. For urbanization level, urbanization rate is still the most prominent and representative, and the citizenization degree has gradually become an important part in improving urbanization level. Thus, urbanization rate was of a higher weight than the citizenization. Moreover, the urban–rural income and consumption gap play an equally important role in measuring urban–rural co-ordination. Similarly, PM2.5 and sewage discharge intensity are of the same weight.

The above socioeconomic data were compiled from the China City Statistical Yearbooks and Urban Construction Yearbooks. We took the Statistical Yearbooks and the statistical bulletins of nine provinces as supplemental materials.

4.2. Calculation of Urbanization Quality

First, the original data were preprocessed by the extreme value normalization method to ensure the comparability of different indicators. The normalized scores were used to evaluate the relative performance of urbanization quality improvement over time. The negative and positive indicators were preprocessed by Formula (1) and Formula (2), respectively:

$$X_{ij} = (\max x_j - x_{ij})/(\max x_j - \min x_j) \tag{1}$$

$$X_{ij} = (x_{ij} - \min x_j)/(\max x_j - \min x_j), \tag{2}$$

where x_{ij} refers to the j_{th} indicator's value in the i_{th} city. $\max x_j$ and $\min x_j$ represent the maximum and minimum values, respectively. X_{ij} is the normalized value.

Second, we aggregated the subdimensional and comprehensive quality scores. A higher score indicates better progress in improving urbanization quality. Specifically, the calculation of subdimensional and comprehensive qualities of i_{th} depends on the following formulas:

$$U_{ik} = \sum_{j=1}^{m} (X_{ij} * \lambda_j), \tag{3}$$

$$T_1 = 0.25U_{i1} + 0.25U_{i2} + 0.25U_{i3} + 0.25U_{i4}, \tag{4}$$

$$T_2 = 0.22U_{i1} + 0.22U_{i2} + 0.22U_{i3} + 0.22U_{i4} + 0.12U_{i5}, \tag{5}$$

where k = 1, 2 . . . . . . 5. λ_j and m represent the corresponding indicator weight and the indicator numbers of each dimension, respectively. U_1, U_2, U_3, U_4, and U_5 represent the value of economic efficiency, urbanization level, urban–rural co-ordination, environmental quality, and agricultural development, respectively. T_1 is the comprehensive quality of urbanization under the four-dimensional indicator system, and T_2 is the comprehensive quality of urbanization under the five-dimensional indicator system.

4.3. Exploratory Spatial Data Analysis

Global Moran's I was used to measure whether the factors have agglomeration characteristics in space and is defined as Formula (6) [62]:

$$I = \frac{n\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}(x_i - \bar{x})(x_j - \bar{x})}{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}\sum_{i=1}^{n}(x_i - \bar{x})^2}, \quad (6)$$

where x_i and x_j refer to the attribute values of region i and j, respectively. $\bar{x}$ denotes the average of attribute values. n is the number of study units. W_{ij} denotes the spatial weight matrix and is used to define the adjacency relationship between spatial units. The value of I ranges between −1 and 1. There is a positive or negative spatial autocorrelation when it is greater than 0 or less than 0. When the value is equal to 0, it means the random distribution.

Since spatial-autocorrelation changes in regions are not necessarily stable, local Moran's I was introduced to analyze agglomeration characteristics of factors from a local level and is defined as Formula (7) [62,63]:

$$I_i = \frac{n(x_i - \bar{x})\sum_{j=1}^{n} W_{ij}(x_j - \bar{x})}{\sum_{i=1}^{n}(x_i - \bar{x})^2} \quad (7)$$

We created maps of the local indicators of spatial association (LISA), and distinguished cluster types with different legends. High–high indicates that both the region and its neighbors have high values while low–low means the region and its neighbors have low values. High–low denotes that region with high values have low-value neighbors. Low–high is the opposite. When the indicator is not significant, it indicates there is no correlation among adjacent regions.

4.4. Coupling Co-Ordination Degree Model

We employed the coupling co-ordination degree to analyze whether urbanization quality in various regions had achieved co-ordinated development. Its calculation was based on coupling degree, which was calculated by the following:

$$C = \frac{5\sqrt[5]{U_{i1} * U_{i2} * U_{i3} * U_{i4} * U_{i5}}}{U_{i1} + U_{i2} + U_{i3} + U_{i4} + U_{i5}}, \quad (8)$$

Coupling degree reflects the correlation level among subdimensions but fails to judge whether the subdimensions are co-ordinated. Thus, to evaluate the overall co-ordination effect more objectively and reasonably, the coupling co-ordination degree model was introduced and calculated by Formula (9):

$$D = \sqrt{C * T_2}, \quad (9)$$

To more clearly and intuitively analyze the coupling co-ordination status of urbanization quality in various regions, we employed the Jenks function in ArcGIS 10.5 to divide the co-ordination degree to achieve the statistical effect with the largest difference between groups and the smallest difference within groups [64]. Based on the data characteristics, co-ordination mode was classified into three categories: good, basic, and low.

5. Results

5.1. Regional Differences in Comprehensive Urbanization Quality

The comprehensive urbanization quality of MGPAs presented an upward trend during 2010–2018. (The analysis of comprehensive urbanization quality was based on the results of five-dimensional evaluation indicator system. The conclusions drawn based on the results of four-dimensional indicator system were similar.) The mean value increased from 0.560 in 2010 to 0.578 in 2015 and then increased to 0.585 in 2018. Between 2010 and 2018, the urbanization quality in 96 cities improved, accounting for 75% of the cities in MGPAs.

Urbanization quality showed obvious regional differences. In terms of provinces, except for Hebei and Henan, the other provinces' urbanization quality improved from 2010 to 2018. Jiangsu's urbanization quality continued to rank first over the study period; its mean value reached 0.703 in 2018, which was 0.12 higher than the average for MGPAs. However, the urbanization quality of Anhui, Hebei, and Henan continued to be lower than the average (Table 4). In terms of prefecture-level cities, urbanization quality in cities of different scales improved over time. Megacities and large cities had higher urbanization quality scores than small- and medium-sized cities. In 2018, the mean value of megacities and large cities was 0.662 and 0.598, respectively. Meanwhile, the mean value of small and medium-sized cities was 0.577.

Table 4. Average comprehensive urbanization quality in 2010, 2015, and 2018.

Areas	2010	2015	2018
Densely populated agricultural areas	0.545	0.570	0.575
Nondensely populated agricultural areas	0.573	0.586	0.595
Hebei	0.513	0.526	0.503
Henan	0.510	0.487	0.507
Shandong	0.578	0.573	0.604
Anhui	0.540	0.573	0.568
Jiangsu	0.668	0.690	0.703
Hubei	0.572	0.597	0.609
Hunan	0.537	0.592	0.589
Jiangxi	0.564	0.594	0.597
Sichuan	0.561	0.594	0.596

Moreover, urbanization quality in nondensely populated agricultural areas and densely populated agricultural areas continued to improve over time. Urbanization quality in nondensely populated agricultural areas was continuously higher than in densely populated agricultural areas (Table 4). In 2018, among cities with an urbanization quality higher than the average of MGPAs, 61% of the cities belonged to nondensely populated agricultural areas. Meanwhile, the top five cities for urbanization quality in MGPAs were Wuxi, Suzhou, and Ezhou (nondensely populated agricultural areas) and Yancheng and Yangzhou (densely populated agricultural areas).

5.2. Temporal and Spatial Characteristics of Subdimensional Quality

The mean values for economic efficiency, urbanization level, and environmental quality increased continuously over time. However, the mean value for agricultural development increased during 2010–2015 and then decreased during 2015–2018. Additionally, the mean value of urban–rural co-ordination continued to decline (Table 5). Specifically, from 2010 to 2018, economic efficiency rose from 0.765 to 0.785, and urbanization level steadily improved, with the mean value rising from 0.416 to 0.506. Average environmental quality increased from 0.555 to 0.585, indicating that MGPAs had recognized the importance of environmental protection and promoted the improvement of environmental quality. The mean value for agricultural development increased from 0.286 in 2010 to 0.306 in 2015 and then dropped to 0.287 in 2018. This indicates that agricultural development has declined in recent years, and attention should therefore be paid to the food security problem. However, the mean value for urban–rural co-ordination decreased from 0.652 to 0.628, indicating that income and consumption gaps of urban–rural residents have been widening.

Moreover, there were differences in the progress toward improving subdimensional qualities between nondensely and densely populated agricultural areas. The values for economic efficiency, urbanization level, and environmental quality in nondensely populated agricultural areas were all continuously higher than the densely populated agricultural areas. The mean value for urban–rural co-ordination in nondensely populated agricultural areas dropped sharply; it was slightly lower than that in densely populated agricultural areas in 2018. Densely populated agricultural areas had relatively high levels of agricultural development, with mean values 0.07 and 0.13 points higher than MGPAs and nondensely populated agricultural areas, respectively, in 2018.

Table 5. Subdimensional quality values in 2010, 2015, and 2018.

Subdimension	MGPAs			Densely Populated Agricultural Areas			Nondensely Populated Agricultural Areas		
	2010	**2015**	**2018**	**2010**	**2015**	**2018**	**2010**	**2015**	**2018**
Agricultural development	0.286	0.306	0.287	0.354	0.379	0.357	0.226	0.240	0.224
Economic efficiency	0.765	0.783	0.785	0.738	0.756	0.759	0.789	0.807	0.809
Urbanization level	0.416	0.457	0.506	0.405	0.451	0.500	0.426	0.462	0.512
Urban–rural co-ordination	0.652	0.642	0.628	0.640	0.642	0.635	0.663	0.642	0.623
Environmental quality	0.555	0.581	0.585	0.503	0.534	0.526	0.602	0.622	0.639

To further analyze spatial heterogeneity, this study used the Jenks function in ArcGIS10.5 to divide MGPAs in 2018 into five levels (Figure 3). Then, we employed GeoDa 1.10 to explore spatial agglomeration characteristics of urbanization quality (Table 6 and Figure 4).

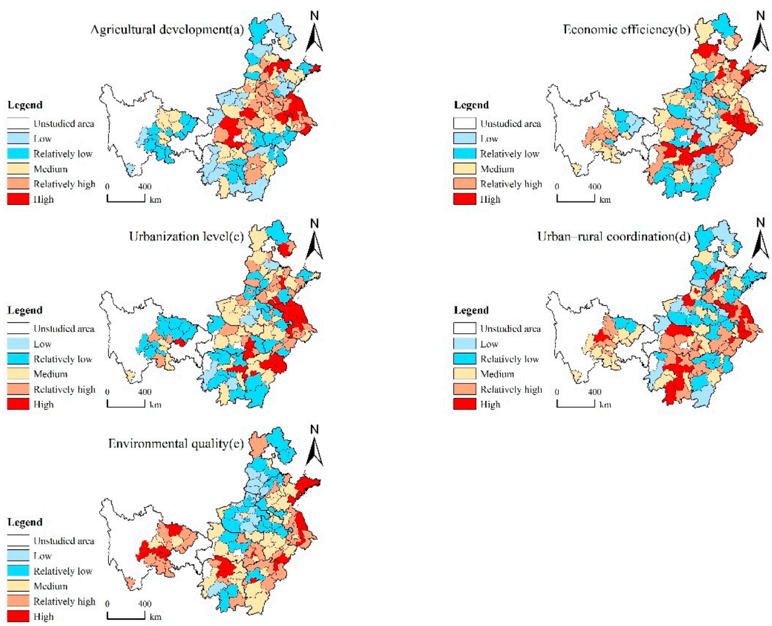

Figure 3. Spatial distribution of the subdimensional quality of MGPAs in 2018.

Table 6. Moran's I of subdimensions in 2018.

Subdimension	Global Moran's I	*p*-Value	Z-Score
Agricultural development	0.428	0.001	7.435
Economic efficiency	0.300	0.001	5.448
Urbanization level	0.175	0.004	3.188
Urban–rural co-ordination	0.182	0.003	3.210
Environmental quality	0.584	0.001	10.419

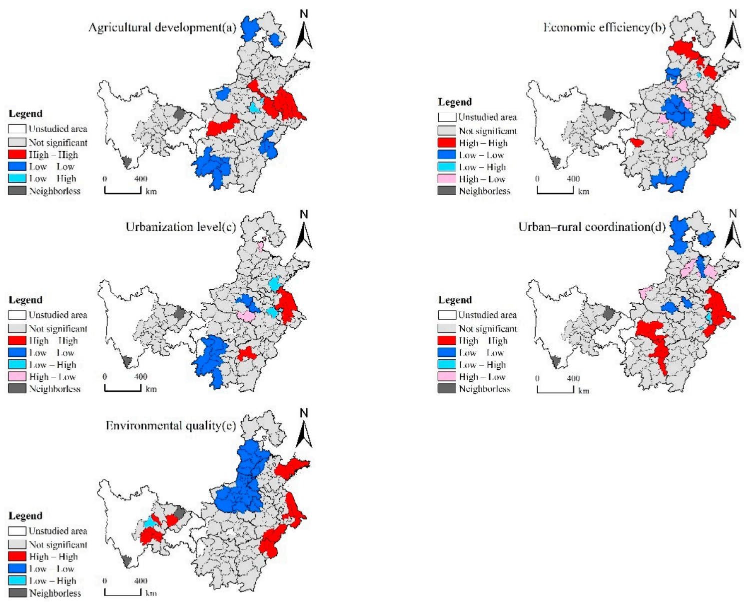

Figure 4. LISA cluster maps for the subdimensional quality of MGPAs in 2018.

It can be inferred from Table 6 that the subdimensions had positive global spatial autocorrelations and presented agglomeration distributions in space. The Moran's I of environmental quality was higher than that of the other dimensions, indicating that environmental quality had the strongest spatial autocorrelation. Meanwhile, urbanization level had the weakest spatial autocorrelation.

For agricultural development, high-value areas presented a centralized distribution in southeastern Henan, northern Anhui, central Hubei, and northern Jiangsu. Low-value areas were centralized in mountainous and hilly regions, such as southwestern Hunan, southern Anhui, northern Hebei, and southern Sichuan. In terms of local spatial autocorrelation, the high–high type was mainly located in Jiangsu, northeastern Anhui, and central Hubei. In addition to Zhangjiakou, Tangshan, Luoyang, Jingdezhen, Shangrao, and Chizhou, cities in southwestern Hunan were of the low–low type. Fuyang and Huaibei were of the low–high type.

For economic efficiency, high-value areas were mainly distributed in Jiangsu, Shandong, southern Anhui, and northern Hunan. Qingdao, Dongying, Wuxi, Changzhou, and Suzhou ranked in the top five. Jiangxi and southeastern Henan, with most of low-value areas located in, should further optimize resource utilization. Economic efficiency showed an obvious spatial agglomeration. The high–high type was concentrated in southern Jiangsu. Baoding, Cangzhou, Weifang, and Binzhou belonged to the high–high type as well. The low–low type mainly gathered in southeastern Henan while the high–low type was scattered. Laiwu was of the low–high type.

For urbanization level, high-value areas were concentrated in Jiangsu, provincial capital cities, and the surrounding areas. Low-value areas mainly gathered in Sichuan and Hunan, and the mean value for Sichuan and Hunan was lower than the average for MGPAs. Urbanization level also had spatial autocorrelation characteristics. The high–high type was centralized in Jiangsu. In addition to Fuyang, Zhoukou, and Luohe, cities in western Hunan were of the low–low type. Xinyang and Langfang were of the high–low type while Linyi and Chuzhou were of the low–high type.

For urban–rural co-ordination, high-value areas mainly gathered in Jiangsu, Hunan, and central Hubei. The mean value for Anhui, Henan, Shandong, Jiangxi, and Hebei was lower than the average for MGPAs. Urban–rural co-ordination showed a trend of spatial agglomeration. The high–high type showed a concentrated distribution in Jiangsu, eastern Hunan, and central Hubei. Zhangjiakou, Qinhuangdao, Tangshan, Baoding, Zhumadian, Binzhou, Zibo, and Bozhou were of the low–low type. Liaocheng, Dezhou, Laiwu, Weifang, and Sanmenxia were of the high–low type. Tongling and Nanjing belonged to the low–high type.

For environmental quality, the high-value and low-value areas showed obvious north–south differentiation. The mean value for the southern cities in MGPAs reached 0.641 while the mean value for northern cities was only 0.481. Low-value cities were concentrated in Henan and Hebei, with Shijiazhuang, Xingtai, Handan, Jiaozuo, and Pingdingshan being the lowest. Therefore, those cities should modify their development modes and attach more importance to environmental protection. As for local spatial autocorrelation, the low–low type was concentrated in Henan and Hebei while the high–high type was concentrated in Sichuan, eastern Shandong, southeastern Jiangsu, southern Anhui, and northeastern Jiangxi. Chengdu, meanwhile, was of the low–high type.

5.3. Urbanization Quality Differences under Two Evaluation Indicator Systems

After agricultural development was added to the evaluation indicator system, the urbanization quality rankings of cities changed greatly (Figure 5). Cities with rising rankings presented a concentrated distribution in densely populated agricultural areas. Cities with falling rankings mainly gathered in nondensely populated agricultural areas. In 2010 and 2018, 57 and 52 cities improved their urbanization quality rankings, among which 79% and 77% were located in densely populated agricultural areas, respectively. Meanwhile, 64 and 68 cities fell in their urbanization quality rankings, of which 79% and 78% were located in nondensely populated agricultural areas, respectively. Only seven cities in 2010 and eight cities in 2018 remained unchanged in the rankings.

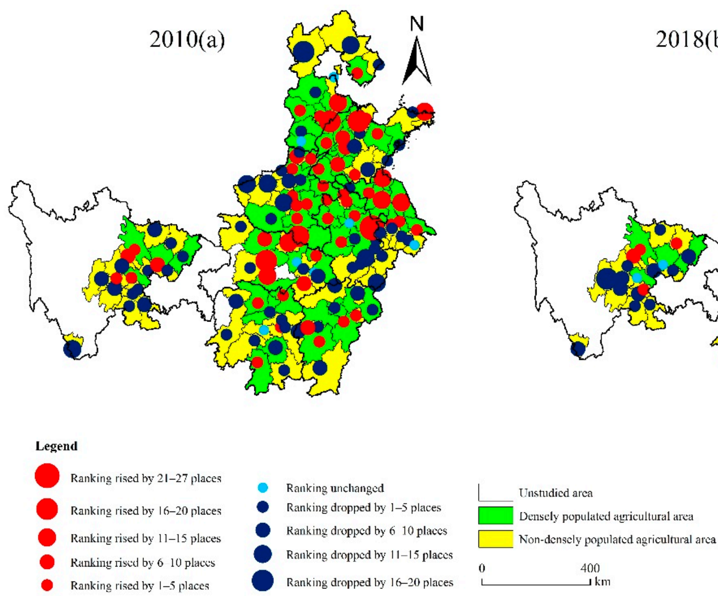

Figure 5. Changes in urbanization quality rankings after adding agricultural development to the evaluation indicator system.

Specifically, among densely populated agricultural areas, the urbanization quality rankings of Jingmen, Jingzhou, Dezhou, Huai'an, Binzhou, and Chuzhou rose significantly in 2018 by 27, 23, 20, 16, 14, and 13 places, respectively. These cities had relatively high levels of agricultural development, and the rankings significantly rose when agricultural development was included in the evaluation system. The number of cities that dropped in the rankings was relatively small, and they only dropped slightly without obvious overall fluctuations. In nondensely populated agricultural areas, the rankings of Ya'an, Laiwu, Zhengzhou, Jiujiang, and Huangshan dropped significantly in 2018 by 17, 16, 15, 13, and 12 places, respectively.

5.4. Co-Ordinated Development Modes of Urbanization Quality

From 2010 to 2018, 88 cities remained unchanged in the co-ordination modes (Table 7). For the good co-ordination mode, there were 12 cities in densely populated agricultural areas and 14 cities in nondensely populated agricultural areas. The subdimensions of urbanization quality in these cities achieved good development and produced good co-ordination effects. Therefore, the good co-ordinated development trend should be stabilized and maintained in these cities to promote the sustainable development of urbanization. For the basic co-ordination mode, there were 19 cities in densely populated agricultural areas and 24 cities in nondensely populated agricultural areas. Initial achievements were made in the subdimensional development of urbanization quality in those cities, and an overall co-ordination effect has gradually appeared. Thus, it is necessary to further improve the development levels of all dimensions to achieve higher levels of co-ordination. For the low co-ordination mode, there were 10 cities in densely populated agricultural areas and nine cities in nondensely populated agricultural areas. Achieving the co-ordinated development of urbanization quality in these cities poses a relatively arduous task.

Table 7. Co-ordinated development modes remained unchanged during 2010–2018.

Mode	Densely Populated Agricultural Areas	Nondensely Populated Agricultural Areas
Good co-ordination	Yangzhou, Huai'an, Xiangyang, Xuzhou, Yueyang, Lianyungang, Changde, Suqian, Nantong, Taizhou, Yancheng, Jingmen	Weihai, Wuxi, Changzhou, Suzhou, Zhenjiang, Wuhan, Yichang, Ezhou, Suizhou, Changsha, Xinyu, Yingtan, Dongying, Nanjing
Basic co-ordination	Xuchang, Jining, Tai'an, Liaocheng, Binzhou, Huainan, Chuzhou, Suzhou, Liu'an, Bozhou, Xiaogan, Hengyang, Yongzhou, Nanchang, Ji'an, Yichun, Mianyang, Nanchong, Dazhou	Langfang, Hebi, Luohe, Sanmenxia, Zaozhuang, Rizhao, Ma'anshan, Huaibei, Chizhou, Huangshi, Zhuzhou, Xiangtan, Jingdezhen, Pingxiang, Jiujiang, Chengdu, Zigong, Luzhou, Deyang, Guangyuan, Suining, Leshan, Yibin, Laiwu
Low co-ordination	Handan, Xingtai, Baoding, Hengshui, Kaifeng, Anyang, Puyang, Shangqiu, Zhoukou, Fuyang	Zhengzhou, Jiaozuo, Linyi, Shiyan, Shaoyang, Zhangjiajie, Huaihua, Ganzhou, Pingdingshan

40 cities changed their co-ordination modes (Table 8). Specifically, 22 cities changed their co-ordination modes to a lower level, among which 11 cities changed from the good co-ordination mode to the basic co-ordination mode, and the other cities changed from the basic co-ordination mode to the low co-ordination mode. The imbalanced development of subdimensions was prominent in these cities. Therefore, the development of relatively lagging dimensions should be promoted. In addition, 18 cities changed their co-ordination modes to a higher level, among which 8 cities changed from the basic co-ordination mode to the good co-ordination mode, and 10 cities changed from the low co-ordination mode to the basic co-ordination mode.

Table 8. Changes in the co-ordinated development modes during 2010–2018.

Mode	Densely Populated Agricultural Areas	Nondensely Populated Agricultural Areas
Changing from good co-ordination to basic co-ordination	Tangshan, Xinyang, Jinan, Qingdao, Weifang, Fuzhou	Zibo, Yantai, Wuhu, Xuancheng, Guang'an
Changing from basic co-ordination to low co-ordination	Shijiazhuang, Cangzhou, Nanyang, Zhumadian	Qinhuangdao, Chengde, Luoyang, Tongling, Panzhihua, Ya'an, Bazhong
Changing from basic co-ordination to good co-ordination	Dezhou, Heze, Jingzhou, Yiyang, Ziyang	Xianning, Neijiang, Meishan
Changing from low co-ordination to basic co-ordination	Xinxiang, Hefei, Bengbu, Huanggang, Shangrao	Zhangjiakou, Anqing, Huangshan, Chenzhou, Loudi

6. Discussion

Food security and urbanization have become important aspects in promoting sustainable development [65]. As the key and typical areas for achieving the SDGs, MGPAs' urbanization should not sacrifice agricultural development and follow other urbanization paths [29,66].

The comprehensive urbanization quality continued to improve over time, indicating a good trend in improving urbanization quality and implementing the SDGs. Meanwhile, the ongoing improvements in economic efficiency, urbanization level, and environmental quality have contributed to high-quality urbanization and the realization of Goals 8, 11, 6 and 12. However, urban–rural co-ordination has declined continuously, making it difficult to achieve overall development of urban and rural areas and reduce regional inequality. Moreover, the decline in agricultural development in recent years will pose a great threat to food security and increase the vulnerability of development [67]. Thus, MGPAs could prioritize urban–rural co-ordination and agricultural development and implement effective policies to facilitate overall improvement of urbanization quality.

Further, MGPAs should fully consider the heterogeneity of regional development. For example, targeted strategies should be formulated to reduce the urbanization quality gap between densely and nondensely populated agricultural areas. The densely populated agricultural areas experienced high-level agricultural development. They should adhere to the arable land protection policies, promote the agricultural technological innovation, and further improve capabilities for food security. Meanwhile, urbanization level and economic efficiency should be improved on the premise of reasonable development scale and intensity. The nondensely populated agricultural areas have relatively weak advantages in the agricultural development and should maintain a certain agricultural foundation and production capacity to provide necessary food support for urbanization. Additionally, it is necessary to improve public service facilities, optimize industrial structure, and promote urban–rural co-ordination.

In addition, the factors leading to the low degree of co-ordinated development varied among cities. Attention should also be paid to the cities with co-ordination modes changing to a lower level. Thus, each city should focus on the lagging dimensions. For example, Shangqiu and Zhoukou, as traditional agricultural areas, maintained relatively high levels of agricultural development. However, their economic efficiency was far lower than other cities, and the urbanization rate and degree of in situ urbanization were low, hindering the co-ordinated development of urbanization quality. Therefore, further promoting industrialization and urbanization should be taken as important strategic tasks.

7. Conclusions

In line with the specific targets of the SDGs related to urbanization, this study established two sets of multidimensional evaluation indicator systems, and analyzed the temporal and spatial dynamics of urbanization quality in China's MGPAs during 2010–2018. Then, we compared cities' rankings before and after adding agricultural development to the evaluation indicator system in order to further examine urbanization quality on the premise of not sacrificing agriculture. Finally, we studied the co-ordinated development modes of urbanization quality. The main conclusions were as follows:

(a) Comprehensive urbanization quality increased over time and showed obvious regional differences. Urbanization quality in Jiangsu was continuously higher than in other provinces. Megacities and large cities had higher urbanization quality than small- and medium-sized cities. Nondensely populated agricultural areas had higher urbanization quality than densely populated agricultural areas.
(b) Regarding subdimensions, economic efficiency, urbanization level, and environmental quality improved during 2010–2018. However, urban–rural co-ordination and agricultural development, with the mean values decreasing in recent years, have become the weak links in achieving high-quality urbanization and the SDGs. Furthermore, subdimensions presented agglomeration distributions in space.
(c) When agricultural development was included in the evaluation indicator system, the urbanization quality rankings of cities varied greatly. Cities with an elevated ranking were mainly concentrated in densely populated agricultural areas while those with a decline in ranking were mainly concentrated in nondensely populated agricultural areas. Among 128 prefecture-level cities from 2010 to 2018, twenty-six cities remained in the good co-ordination mode; forty-three cities remained in the basic co-ordination mode; and nineteen cities remained in the low co-ordination mode. Eighteen cities' co-ordination modes turned to a higher level, while twenty-two cities' co-ordination modes turned to a lower level.
(d) MGPAs should be guided by SDGs to undertake the important task of ensuring national food security and promoting new urbanization [68]. MGPAs need to improve land utilization, especially in nondensely populated agricultural areas, and focus on the problem of occupying cultivated land in densely populated agricultural areas. Moreover, MGPAs should promote cleaner food production. The degradation of cultivated land resources in MGPAs is partly due to the excessive use of chemical fertilizers, pesticides, and herbicides, which not only seriously damages the ecological environment and affects the quality of grains, but also increases production costs. Last but not least, compensation and subsidy policies for MGPAs' grain production should be enlarged.

This study helps to enrich the evaluation indicator system, understand the urbanization quality with regards to MGPAs in detail, and provide a basis for formulating differentiated policies in different regions. It can also offer a reference for both improving urbanization quality and achieving the SDGs in developing countries. Improving the evaluation indicator system and exploring the mechanism of differences in urbanization quality warrant attention in further research.

However, this study has some limitations. First, because of the availability of data, the study period only includes 2010–2018. Second, this study only considers the degree of coupling and co-ordination between agriculture, food security, and urbanization, but they have a complex coupling, decoupling, and recoupling relationship, just like other SDGs researches, and they have an urgent need for further study [33]. Therefore, future research will further consider extending the research period to further explore the complex relationships. More importantly, because the COVID-19 pandemic has made the world deeply aware of the importance of food security, future research will incorporate new factors into the analytical framework.

Author Contributions: Conceptualization, F.G., C.M. and W.S.; methodology, F.G., C.M. and W.S.; software, F.G., J.Z. and L.Y.; validation, F.G., C.M. and W.S.; formal analysis, C.M. and W.S.; resources, J.Z. and L.Y.; data curation, J.Z. and L.Y.; writing—original draft preparation, F.G., C.M. and W.S.; writing—review and editing, J.Z. and L.Y.; visualization, F.G.; supervision, C.M. and W.S.; project administration, C.M. and W.S.; funding acquisition, C.M. and W.S. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the National Natural Science Foundation of China (Fund project host: Miao Changhong), grant number 41430637; The National Natural Science Foundation of China (Fund project host: Miao Changhong), grant number 42171186.

Institutional Review Board Statement: Not applicable.

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

Data Availability Statement: The data used in this paper mainly come from the Hebei, Henan, Shandong, Anhui, Jiangsu, Hunan, Hubei, Jiangxi, and Sichuan Statistical Yearbooks. The PM2.5 dataset comes from the China Atmospheric Pollutant Dataset. Most of the data can be obtained by visiting the following links: https://data.cnki.net/Yeabook/Navi?type=type&code=A, http://www.gedata.cn/data/idex.html?word (accessed on 1 April 2022).

Acknowledgments: Informed consent was obtained from all subjects involved in the study.

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

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Review

The Interaction between Urban and Rural Areas: An Updated Paradigmatic, Methodological and Bibliographic Review

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Abstract: The relationships and interactions between rural and urban spaces have long been of interest in the territorial sciences. However, the approaches taken to these questions have evolved in line with the changing characteristics of the two types of territories, reflecting new relationships and structures. From these premises, we update the concept of rural–urban interaction by means of an extensive bibliographic review, which, among other results, highlights: (1) the profound change that has taken place in recent years in rural–urban interaction through processes such as de-agrarianisation, the tertiarisation of the economy and improvements in transport and communication infrastructures; (2) the resulting obsolescence of earlier typologies and procedures focused on discrimination between rural and urban environments, rather than on the interaction between them; (3) the difficulty of establishing valid, widely applicable typologies, given the profound differences in terms of (a) the scale and content of the statistics available in each country and (b) the territorial background in terms of economic functions and the characteristics, ancient and modern, of human settlement; (4) the predominance of an urban-centric approach, to the detriment of more traditional rural functions, such as agriculture, the importance of which is diluted by its low relative weight in terms of employed population and contribution to GDP. Consideration of these findings leads us to propose a new approach to the question of rural–urban interaction, reflecting the multifunctionality of rural spaces, and we identify useful areas for future research.

Keywords: urban sprawl; rural–urban integration; countryside urbanisation; deagrarianisation; land use

Citation: Delgado-Viñas, C.; Gómez-Moreno, M.-L. The Interaction between Urban and Rural Areas: An Updated Paradigmatic, Methodological and Bibliographic Review. *Land* **2022**, *11*, 1298. https://doi.org/10.3390/land11081298

Academic Editor: Tao Liu

Received: 11 July 2022
Accepted: 2 August 2022
Published: 11 August 2022

1. Introduction

Any study of rural–urban relations and interactions requires the fundamental assumption that some spaces can be classified as "urban" and others as "rural". Although this is indeed true, urban and rural areas do not constitute two separate territories that can be considered in isolation. On the contrary, they are strongly interrelated in many ways, and their connections must be investigated, theoretically and empirically, in terms of identity, causality and effects.

Terms such as *rural* vs. *urban* and *the country* vs. *the city* are commonly used to identify the main types of geographical spaces, both in academic circles and colloquially. Defining them, in both cases, usually involves a simplifying conceptual approach to address interdependent and complementary realities, focusing on the main features of their interconnections; hence, the numerous and continuing attempts to derive an almost impossible conceptual delimitation that, until recently, and especially in the case of rural spaces, usually lacks completeness and accuracy [1,2].

In recent decades, studies of territorial transformations have mainly focused on urban spaces, an interest that is understandable in the present era of planetary urbanisation. In contrast, rural spaces have been relegated to a subsidiary plane, except for issues related to sustainable development. This division of attention persisted until long-standing problems in the rural environment, such as economic recession, falling agricultural potential, population aging and demographic decline, intensified and threatened to become entrenched. In parallel, the rise of globalisation has increased the distance between where food and raw materials are produced and where they are consumed. The great paradox of this situation is that massive urbanisation has led to a world in which 55% of the population lives in urban areas, a proportion as high as 80% in high-income countries (U.N.); moreover, 80% of the land surface is employed for purposes that are fundamental to the biosphere and to human existence.

It is not our intention here to enter into the knotty question of defining rurality and urbanity, a topic that has been addressed in different ways in diverse areas of knowledge. The literature in this respect is comprehensive and well-attested [3–9]. Although the epistemological debate remains open and is of great interest, we believe the present analysis is not the most appropriate context for an in-depth consideration. Accordingly, we adopt the standard spatial definitions of rurality and urbanity, particularly those that are most recent and suited to the current reality, using them pragmatically as a means of addressing the economic, demographic and territorial structures of rural spaces.

The research project from which this article is derived was undertaken to provide reasoned, well-founded answers to the following questions:

- How have epistemological and methodological approaches in territorial sciences, especially geography, evolved in terms of the interactions between rural and urban spaces?
- What factors underlie recent changes in these approaches?
- Have changes in territorial realities modified the approaches taken and methods used to analyse rural–urban interactions?
- Are obsolete perspectives and methods, unrelated to current territorial realities, still encountered?

For the present, our main study aim was to consider the evolution of the various approaches taken to address the increasingly complex relationship between urban and rural areas and the ways in which one type of space—specifically, urban areas—has influenced the transformation of rural spaces. It is not our intention to establish new theories but to synthesise the dynamics of those currently proposed. To do so, we have compiled an extensive selection of the most important published references on this subject, both in general and for each approach and perspective in particular. By these means, we hope to endorse the results obtained and make this validated information available to future researchers in this field

To achieve these objectives, we adopted a qualitative methodological process based on: (1) selecting concepts, notions and terms concerning rural–urban relationships and interactions; (2) reviewing the scientific literature related to these conceptual elements; (3) compiling the main texts from the academic literature on this subject from the mid-20th century to the present day; (4) reading these texts and performing a critical analysis and synthesis of the approaches and perspectives described in the literature, as well as determining a typology of these approaches and of their temporal and special dynamics; and (5) making a critical selection of the methods that are currently being applied most commonly and effectively to analyse and interpret rural–urban relations and interactions.

On the basis of this review, we: (1) explain and clarify this conceptual evolution within the framework and context of real-world territorial dynamics, revealing the coherence between theory and reality at each stage; (2) systematise the main variables and, from this, analyse the features of rural–urban interactions, discussing the advantages and shortcomings of each method used to study them; and (3) propose new forms of analysis appropriate to the greater complexity now presented by this interaction.

2. Results

2.1. Interaction between Rural and Urban Spaces: Updating the Theoretical Framework

The terms “rural” and “urban” refer to spatial realities that have often been interpreted as opposed, or even antagonistic and divergent [10,11], from a dichotomous binary perspective based on alterity to the urban environment. This approach not only represents a simplification in various respects but also expresses a non-existent homogeneity of rural and urban spaces, as if there were only one model of each category.

The spatial reality is much more complex than the above notion. Moreover, this complexity is increasing, and a complete understanding of the question would require multiple interdisciplinary analyses. This is particularly so today, when hybrid spatial environments [12] and numerous multifunctional rural landscapes are taking shape [13]. Although the most intense interactions are taking place in rural spaces that have become integrated into functional urban and peri-urban areas, rural spaces that are more distant or less well connected with urban ones are also experiencing the impact of cities, albeit indirectly; for example, as falling levels of population caused by rural–urban migration [14].

As regards the first aspect, many rural areas are now witnessing the birth of a distinct spatial reality. The term "new rurality" [15–18] refers to the reconstructed forms of organisation and the functional transformations being observed in spaces that previously had a rural identity and that are now evolving towards a different category of rural space [19,20]. Although the meanings assigned to this term by different theorists do not always coincide—in particular, there are significant conceptual differences between European [21] and Latin American authors [22–28]—it is generally accepted that the essential features of this "new rurality" consist of an increased mobility of people and goods, the diversification of economic activities and a modification of land use [29,30].

A major socioeconomic transformation that has taken place in many areas is that of "deagrarianisation" [31–38], or a reduction in the importance of agrarian activities, in terms of employed population and income and the correspondingly greater weight of non-agrarian forms of occupation. Deagrarianisation leads to a progressive loss of traditional ways of life, such that agrarian activity ceases to constitute the economic base and the main hallmark of rurality. It is a process that responds to the new productive and territorial logics of the globalised economy and has been associated with deruralisation [39] from a perspective based on the premise—quite questionable in our opinion—that the rural environment can be fully identified with agricultural activity. As concerns Spain, deagrarianisation [40–42] has been cited among the structural causes of the rural exodus, with particular reference to the modernisation of agrarian activity [43]. For this reason, it is often viewed as an effect that is generalised and not exclusive to urbanised rural areas.

Another significant change, as a general rule complementary to the above, is the shift in patterns of employment and economic activity towards the services sector, together with the acquisition of a subsidiary residential function with the construction of second homes for the urban population [44–46].

The historical interaction between rural and urban spaces has evolved incessantly, profoundly transforming relations between the countryside and the city [47] and blurring the boundaries between urban and rural environments. Nevertheless, significant differences remain, and few authors question the existence of a rural–urban divide. Moreover, scholars have observed the gradual consolidation of fissures between different types of rural spaces [48–50], although they may be concealed by the regular occupational mobility of a large part of the rural population [51,52].

It is almost universally acknowledged that the main driver of these changes is "rural urbanisation". This process has many consequences, including the physical modification of the territory and changes in its socioeconomic structures [53–55]. This urbanisation is functional, morphological, landscape-based and cultural, and it takes place not only in areas bordering or readily accessible to large cities but also in more remote territories and those bordering medium-sized and even small cities [56–58], which thus configure micropolitan areas [59].

The fact that urbanisation processes are the main factor triggering the territorial mutations that have occurred in many contemporary societies [60–62] explains the primacy of the urban-centric standpoint that has been adopted in most studies of rural areas, both past and present [63,64]. Thus, it is very widely accepted that the revitalisation of rural spaces takes place via logics according to which they are modified physically and socially. These logics, moreover, impact the strategies used to obtain the economies of urban agglomeration, such as spatial externalities, from which some rural areas also benefit [65–70]. In contrast, other spaces, generally those in peripheral and marginal locations, may suffer adverse effects from backwash, a process associated with the centre–periphery paradigm [71–81].

The urban-centric notion is also related to numerous concepts and words that have been coined to define the changing relations between rural and urban environments: "suburbanisation" [82,83], "peri-urbanisation" [84,85], "rurbanisation" [86–88], "exurbanisation" [89], "rural urbanity" [90], "rural gentrification" [91–93], "urban countryside", "infiltration of the city into the countryside" [94], etc. In addition, some of these terms are closely related to a process that has been termed "counter-urbanisation" [95–98]. The proliferation of recent studies addressing these concepts highlights their conceptual interest and underlines the presence of a renewed dialogue between rural and urban geographies.

Another relevant consideration is the territorial concept of a sprawltown [99–101], also identified as "*città diffusa, campagna urbanizzata*" [102–110], characterized by the absence of vertical territorial hierarchies from the centre to the periphery, which are replaced by horizontal connections among population centres and by the dispersion of functions [111,112].

It is now widely accepted that the former elements of differentiation between urban and rural contexts have ceased to be operational and that alternative approaches to spatial realities are required. One such approach involves the functional integration of the two types of geographical space, whose signs of identity, such as agricultural activities, are weakening but have not entirely disappeared [113]. One outcome of these changes is the creation of multifunctional spaces and hybrid landscapes [114–116], ambiguous spaces in which urban and rural characteristics fade or even disappear as clearly legible spatial units within the landscape [117–119].

Recent studies of these questions have adopted a more fully integrated perspective of geographic space, going beyond the dichotomous standpoint, which many believe reflects an anachronistic static perspective [120–132].

Geographical space has long been viewed and analysed as a continuum, containing a gradual transition from urban to rural and vice versa, without remarkable territorial discontinuities [133]. However, this interpretation has been challenged by some authors [134] and updated and reformulated by others [135–137]. Nevertheless, for most experts, the concept of a spatial continuum is accepted as a gradient of levels of urbanity/rurality [138] or as cyclical phases of urbanisation [139].

Some authors even deny the usefulness of traditional terminology for different types of spaces (suburban, peri-urban and rururban), claiming that what has been configured is a new model of the disassociated city that is post-industrial or even post-urban [140–145], which should be viewed as a joined-up mosaic of urban elements within a territorial matrix [146] as the result of "metastatic metropolitanisation" [147–149].

The question of how rural and areas are interrelated has attracted growing interest since the end of the twentieth century [150], and increasing numbers of studies have been undertaken in this regard, influencing socioeconomic and land-use planning policies for rural areas and leading to the adoption of new paradigmatic and methodological approaches. This new standpoint might be seen as a "rejuvenation" of rural geographic studies, based on a scientific and epistemological renewal achieved through dialogue and debate among rural and urban researchers seeking to enhance our understanding of developments in this area [151]. Although the contemporary approach to rural geography maintains some classical criteria, it also reveals new perspectives and takes increasing interest in the diverse practices and representations of the rural environment and its inhabitants [152–154].

This evolving research focus first became apparent in the United States and Europe [155–171] and then later in Latin America [172–179], and it is currently becoming accepted in Asia, especially in China [180–183]. In the latter country, following the accelerated urbanisation of the countryside under the model of state capitalism applied in China since the late 1970s [184], dramatic changes have taken place in land use, with a large-scale conversion from agrarian to urban practices. This development has attracted the attention of numerous researchers from different areas of knowledge, including geography, economics and the environmental sciences [185–190].

Numerous recent studies have analysed and interpreted the functional territories [191] resulting from rural–urban integration or hybridisation [192–195] in the area termed the "rural-urban fringe", viewed as a space with its own unique characteristics [196,197]. This entity has also been described as the "urban-rural interface" and as being composed of urbanised rural areas, intermediate territories, in-between territories (TiBs), the territories of a new modernity [198,199] or "hybrid geographies".

Most studies of these questions have focused on the territorial transformations arising from economic and technical changes (deagrarianisation and tertiarisation, in particular) in the distribution of services and production centres, in physical and virtual accessibility and, especially, in mobility [200].

On the other hand, some recent analyses of rurality and urbanity [201,202] continue to address quantifiable data such as population size [203–207], population density and/or distances between settlements of different categories [208,209]. However, these indicators are relatively ineffective as a means of describing rurality [210–212], even the multivariate ones incorporating not only population density but also factors such as demographic dynamics, mobility patterns, migrations and distances to major service centres [213–217]. Very few analyses have also used geographic information techniques for territorial measurement [218,219].

It has been observed that the effects of the urbanisation of rural spaces should be considered according to the specific conditions of both the rural and the urban spaces in which the process takes place [220]. The rationale for this is that the dynamics of urbanisation do not occur in the same way or with the same intensity in all territories. In recent times, both the variety and the complexity of rural spaces have intensified; some are evolving dynamically, while others are characterised by stagnation and decline.

2.2. Epistemological Results: Systematisation of Sources and Methodological Procedures

According to Nelson et al. [9] (p. 352), "Given that situational contexts of the rural vary across the globe, as well as within individual countries, and that different rurality definitions have different purposes, it is widely acknowledged that there is no single index, set of factors, or scale". Accepting this statement as a premise, in this section we systematise the methods and sources applied in the diverse texts reviewed in the previous section. In the Discussion section, this systematisation is used to analyse the advantages and disadvantages of these methods and sources for studies of the rural–urban interaction. Our analysis then focuses on the approaches based on socioeconomic variables—that is, excluding perceptive and cultural approaches—seeking to achieve the following main goals: (1) a series of tables systematising the indexed variables, thresholds and scales observed; (2) a justification of their analysis in the study of rural–urban interactions. The outcomes of this systematisation are summarised below.

2.2.1. When Available Sources Are the Main Conditioning Factor

As shown in Table 1, the sources were systematised into two large blocks, those of a statistical nature (Table 2) and those related to different forms of digitisation.

Table 1. Index of the sources used, based on the literature consulted.

KIND OF SOURCE			SUBJECT
Level 1	**Level 2**	**Level 3**	
Georeferenced information	Geocoded data	Microdata [203]	Demographic and economic data
		Population density in raster format [201]	Rural–urban continuum
	Maps	Road network map [201]	Calculating accessibility
		Map showing population centres with >50,000 inhabitants [201]	
		Digital terrain map [201]	
		Supervised classification of Landsat images [201]	Rural–urban continuum
		CORINE land cover [9]	"Close to nature" land uses
	Big data	Cell phone and remote imaging data [9]	Movements of goods and people
Statistics	See Table 2		

Table 2. Concept indices and variables applied, according to our literature review.

Concept Index 1	Concept Index 2	Variable
Spatial distribution of the population	Settlement and Urban system	Density [204,211]
		Number of inhabitants in the nucleus [202,204]
		Existence or otherwise of city [204]
		Urban cluster
	Proximity or otherwise to metropolitan areas [204,211]	Being adjacent or otherwise [204]
		Commuters [204] Local [203] Intraregional [203] Extraregional [203]
		Mean distance to areas with a large surplus of workplaces in 2004 [203]
		Accessibility to services, measured in driving time [9,202,203,211]
		Mean distance to motorway [203]
		Access to land and maritime infrastructures, such as highways, railroads and ports [9]
		Number of urban centres to be crossed to reach an urban nucleus [203]
Demographic dynamics		Population growth [9,202,203,211]
		Migratory movements [202]
Age structure	[202,203]	

Table 2. *Cont.*

Concept Index 1	Concept Index 2	Variable
Economic activity	Job opportunities [202,203]	Workplace evolution 1994–2004 [202]
		Employment/unemployment rates [9]
		Rate of self-employment (%) [9]
	Skills	Level of education [9,211]
		Skilled manpower [203]
	Diversification of the productive fabric	Number of workers per sector [203,211]
		Non-agricultural jobs [9]
		Population employed in service sector (%) [9]
		Population employed in professional and real estate services [9]
		Population employed in medical and dental professions [9]
		Population employed in entertainment and recreation services [9]
		Population employed in public sector [9]
		Population employed in retail trade [9]
		Number of establishments per sector [204]
	Agricultural structures	Farm owners [204]
		Agricultural production [9]
		Land area dedicated to agriculture [9,203]
	Labour productivity [202]	
Land use		Change in use [211]
Infrastructures		Road conditions [9]
		Land and maritime infrastructure [9]
Other parameters	Income [204]	County [204]; household [9,211]
	Revenue [204]	
	Number of pensioners [9,211]	
	Persistent poverty [9]	
	Number of local newspapers [9,211]	

The former, which are detailed in Table 2 below, are the subject of a very useful discussion for our study purposes. Nelson et al. described the dependency between procedures and results, and the characteristics of available sources, as follows [9] (p. 352): "frequently the selection of specific variables for rurality measures is not explicitly grounded in a guiding theory or conceptualization of the rural, and may perhaps be more a reflection of conveniently available data than an actual representation of the nature of rurality for a specific location". This circumstance has various consequences that affect the reliability of the results:

(i) One is the impact of temporality. This aspect is not usually included in typologies or studies of rural–urban interaction, which are predominantly focused on obtaining a representation at a given time. However, according to Johansen et al. [203], the historical perspective, at least in the medium term, is of essential importance to achieve an understanding of the different situational contexts that may arise. Another important consideration is that the most common statistical sources (censuses) are usually decennial, which, although very appropriate for monitoring changes in the medium term, are often inadequate for determining the situation at a given moment.

(ii) It is also important to consider the question of scale, which has various impacts. The first of these is the fact that, in every country, the boundaries established for territorial administration influence the statistical information compiled, meaning that any studies of rural–urban interaction are subject to inconvenience or bias in this respect. Issermann [204] remarked on the problems arising from the combination of different forms of rural–urban interaction within the same spatial unit. Another dimension of this problem concerns the situational context. In this respect, diverse types of identification are applied, such as the county in the USA and the TL3 level in the OECD classification (equivalent to the juxtaposition of several counties). The proposal by Johansen et al. (referring explicitly to the Danish context) is a good example of a typology for characterising territorial construction, identifying the "parish" as the basic element for the analysis of rural–urban relations. Although, strictly speaking, this concept cannot be extended to other countries, since it indiscriminately mixes administrative terms (such as the commune) with customary terms (parish, locality), the following very appropriate observation is made: "the size of the rural unit had, as a starting point, that the size should be sufficient to capture local identity and culture". In contrast, if the question to be identified is the capacity of urban centres to include rural areas in their sphere of influence, the necessary scale must be increased, highlighting radial distances to outlying areas, the corresponding travelling times and the numbers of persons regularly commuting, as shown in Table 2.

The second impact regarding scale is the type of information available. There is a directly proportional relationship between information detail, especially in terms of economic activity, and the spatial concentration of the population—thus, the greater the number of inhabitants, the greater the detail of productive specialisation. It follows, therefore, that for rural populations, which, as discussed below, are associated with low population volumes, there is a lack of detailed information on their economic activity. Consequently, the data sources needed to measure the interactions between rural and urban activities are inadequate or absent. In this regard, too, another limitation should be noted: the type of information available also depends on the corresponding administrative body, which often filters and supplies data according to its own interests and objectives.

Awareness of the above limitations, in parallel with the availability of alternative data sources derived from the application of new information technologies, particularly the possibility of linking data in real time to their georeferencing coordinates (geographic information systems and big data), has fostered the inclusion of these sources among those used to calibrate the rural–urban relationship. As can be seen in Table 1, they can be used in various ways. In chronological order, remote sensing applied to land uses provides a highly detailed view of the degree and morphology of urban land use (including factors such as housing density and complementary facilities) and of agrarian soil use, indexed in such a way as to reveal plant and crop types and their degree of naturalness. Basic mapping is the usual means of measuring urban accessibility, in terms of the hierarchical network of roads and transport infrastructures. However, the incorporation of digital terrain models greatly increases the accuracy of this information. A recent innovation is the georeferencing of statistical data. Organisations that make use of this facility can make their analysis independent of the administrative units concerned. Finally, although it is still at an early stage of development, the analysis of big data referring to the movements both of persons and of goods offers great potential.

2.2.2. Typologies and Thresholds: Interaction or Segmentation?

As described more generically by Nelson et al. [9], the relevant variables can be entered into a procedure for classifying spaces (at a given scale) by means of quantitative systems that may be more or less complex (multivariate analysis vs. the arrangement of criteria in contingency tables, respectively). This categorisation procedure has benefits that are both practical—for example, spatially identifying where specific corrective measures need to be applied in order to alleviate inequalities between urban and rural spaces—and academic—identifying the spatial distribution of the above-mentioned types of rurality. Closely linked to these typologies are the thresholds corresponding to each of the ranges identified.

(i) Our literature review corroborates the observation by Nelson et al. [9] that widely varying thresholds are used in discriminating urban from rural areas and leads us to conclude that these typologies have limited validity as an instrument of analysis since the meaning of these thresholds is largely dependent on the context from which they are derived. Moreover, in line with the above observations, both the scale and type of resource considered impact the thresholds and, therefore, the typologies established.
(ii) Another fundamental application of threshold analysis is to interpret the distributions of the values obtained. A priori, negative extremes, for variables such as employment, demographic dynamics (depopulation), skills levels and accessibility to basic services, are often considered indicative of predominantly rural areas. And that is why US institutions and the OECD focus on these measures to detect spaces where remedial public policies need to be implemented.

Another approach, proposed by Issermann, is to focus on rural–urban interaction rather than rural–urban discrimination [203]. This interaction, too, can be derived from the variables linked to the concepts of centrality and the urban system (see Tables 3 and 4); i.e., adjacency or otherwise to the metropolitan area (or urban core, or the town per se), although with more detailed thresholds and intervals (from >1 million to <2500 inhabitants).

Table 3. Classification of counties according to the Rural-Urban Continuum Codes of the US Department of Agriculture. Criteria applied and values obtained.

Adjacent to a Metropolitan Area	**Inhabitants (n)**					
				Urban Population		
	>1,000,000	**250,000 to 1,000,000**	**<250,000**	**>20,000 to >250,000**	**>2500 to 19,999**	**<2500 or Completely Rural**
	(1) Metropolitan county	(2) Metropolitan county	(3) Metropolitan county			
Adjacent				(4) Non-metropolitan county	(6) Non-metropolitan county	(8) Non-metropolitan county
Non-adjacent				(5) Non-metropolitan county	(7) Non-metropolitan county	(9) Non-metropolitan county

2.2.3. Variables

Based on Table 2, these are the concept indices and variables applied, according to our literature review:

(i) The settlements and the urban system. The influence of some of the paradigms of quantitative geography on the measurement of and knowledge about rural–urban interaction has led to the above-mentioned predominance of approaches based on the capacity of urban centres to organise the population and function as a hub for the territory. Many studies in this area construct a hierarchy of population centres in terms of the number of inhabitants, the presence/absence of services, their area of influence (measured by numbers of commuters), whether or not they are adjacent to a metropolitan area and the travelling distance/time involved. However, recent processes of counter-urbanisation and peri-urban diffusion have reduced the value of the above approaches, leading analysts to resort to graphic sources or big data.
(ii) Accessibility and transport infrastructure. For an urban space to become an activity hub, it must be accessible both to economic activity (resident workforce and commuters) and to services. In turn, this accessibility depends on the amount and type of

transport infrastructure available (roads, railways, ports, airports and transport links). When such a hub develops significantly, this can generate urban sprawl, both nearby (by fostering commuting) and at a distance (with the increased presence of second homes related to holiday tourism).

(iii) Economic activity. This parameter can be studied from various perspectives. One is that of employment opportunities, the number and diversity of which are always assumed to be greater in urban than in rural areas. Another is the composition of the productive fabric, for which two complementary variables may be examined: the activity sectors of the employed population and of the business establishments (classified in Spain by the CNAE code). The above-mentioned concept of commuting refers to the dissociation between the place of residence and that of employment, which is one of the characteristics of the post-productivist evolution highlighted in our literature review, together with the predominance of tertiary activities, even in population centres with relatively few inhabitants. The skills level of the population, considered either as a whole or only as that of the employed population, can also be included among this set of variables, as this factor can be viewed as one of the causes of the lower occupational expectations of the rural population. With respect to employers, Issermann [203] considered their classification as rural or urban according to their location (the population rank), rather than focusing on the activity itself, an approach that warrants further discussion. Brezzi et al. [201] included labour productivity among the OECD parameters but did not specify the measures to be used. In contrast to the generally uniform approach adopted regarding the above variables, agricultural activity has been examined in diverse ways, with studies focusing on different parameters. For example, with respect to the number of farms, some authors measure agricultural production and associated land uses but do not include the interaction between rural and urban environments via the reciprocal supply of food and raw materials. Another approach [202] is based on the presence and/or proximity of natural spaces, defined by their use according to the CORINE classification system, with respect to urban areas. In this case, the agricultural function is expressly excluded under two initial premises. The first is that "understanding rural-urban interdependencies should include the rural ideal, which is the state of being 'close to nature'". The second is the strengthening of the 'feeling for the territorial community and associated social relations'.

(iv) Changes in land use. This parameter is not considered among the economic variables, since it includes many of the factors and processes discussed above. Its meaning in this respect is clarified in the sources section.

(v) Natural and spatial demographic dynamics—indices of population aging. Demographic vitality is an indicator that is commonly used to measure the effects of rural depopulation (via natural population decrease and high rates of aging). Other factors considered include the functions of peri-urban municipalities in metropolitan areas, particularly with respect to patterns of immigration among young families (which present high rates of natural growth and a population pyramid biased towards the young). Among the studies consulted in our literature review, the ratios used were limited to those of real population growth (in which respect only Brezzi et al. [201] examined migratory movements, using OECD-recommended parameters), indices of aging and the age structure of the population.

(vi) Personal incomes. The identification assumed between rural spaces and marginality explains analysts' use of persistent poverty or personal income as an indicator of population imbalances and inequalities. However, wide variations exist in how these parameters are focused (per capita or per household), the scale used (for example, the county or the commune) and the method of calculation (GDP, income or tax information). Other data sources used to analyse this concept are derived from the relation between aging and retirement, such as the ratio of the number of pensioners to the size of the rural population.

Table 4. Classification of counties according to the Urban Influence Codes, as modified by Isserman [203] (p. 481): criteria applied and values obtained.

Adjacent to Metropolitan Counties	Size of Metro Area		Inhabitants (n)					
			>1,000,000	250,000 to 1,000,000	<250,000	Settlement		
			Large Metro Area	**Small Metro Area**	**Micropolitan Area**	**Non-Core**	**Non-Core with Own Town**	**Non-Core with No Own Town**
			1.	2.				
	Large	Yes			3.	4.		
	Small	Yes			5.		6.	7.
	Any metro	No			8.		11.	12.
	Micropolitan area	Yes					9.	10.

Meanings of the numbers: 1. In large metro area of 1 million residents or more, 2. In small metro area of less than 1 million residents. **Non metropolitan counties:** Micropolitan counties: 3. Adjacent to large metro, 5. Adjacent to small metro, 8. Not adjacent to a metro area, Non core counties: 4. Adjacent to large metro, 6. Adjacent to small metro, with own town, 7. Adjacent to small metro, no own town, 9. Adjacent to micro metro with own town, 10. Adjacent to micro metro, no own town, 11. Not adjacent to a metro or micro area with own town, 12. Not adjacent to a metro or micro area, and no own town.

3. Discussion and Conclusions

In recent decades, studies of territorial transformations have mainly focused on urban spaces, an interest that is understandable in the present era of planetary urbanisation. In contrast, rural spaces have been relegated to a subsidiary plane, with the exception of issues related to sustainable development. This division of attention persisted until long-standing problems in the rural environment, such as economic recession, falling agricultural potential, population aging and demographic decline, intensified and threatened to become entrenched.

However, since the 1990s, interrelated social movements defending food sovereignty and proximity agriculture have denounced the climate change effects caused by the long-distance transport of goods and have proposed alternatives based on matching supply and demand between urban populations and their rural surrounds. Very recently, the weaknesses of the current system have been highlighted by two devastating events, first the COVID-19 pandemic and, subsequently, the international instability arising from the Russian invasion of Ukraine.

Thus, virtually all food production is subject to decisions taken in farming establishments located in particular social environments. However, the function and analysis of these environments are diluted within the concept of "rural spaces". These spaces are very often considered to be marginal because of their weak demographic weight. Nevertheless, their productive function is of great strategic importance to other areas, supposedly more dynamic and attractive for population flows and investments.

To summarise our final thoughts on this compilation and review of the scientific literature considered, it seems apparent that numerous research studies of rural spaces have been published, each taking a different approach and addressing specific areas of knowledge, and that some of the perspectives adopted in this field are changing in interesting ways. For example, scholars are increasingly focusing on the transformations produced in rural areas by the impact of urban activities, either nearby or further afield, when good connections exist.

Of course, the changes that have taken place in rural and urban environments have inevitably impacted the conventional paradigms discussed above. For example, the evolution in rural–urban interactions has heightened scientific interest in rural spaces, both the traditional ones and those that have been transformed. In consequence, recent studies in this area have proliferated. Indeed, it has been affirmed that this new outlook may represent a "rejuvenation" of rural studies, based on "scientific and epistemological renewal", thus creating a fruitful dialogue between rural and urban researchers, facilitating an accurate understanding of these transformations. In this respect, several studies have been undertaken to examine and interpret the multifunctional territories resulting from rural–urban integration or hybridisation in "rural-urban functional fringes", interpreted as areas with their own identity.

Likewise, one of the most significant conclusions drawn from our own study is that the epistemological debate has moved on from a binary, antagonistic interpretation of geographical space towards approaches recognising the complementarity and subsidiarity of both types of territory. The former understanding of rural space as the simple negative image of urban space, with a unifunctional character (as a rule, agrarian), has been replaced with a new outlook, in which the rural environment is seen as something complex and multifunctional. Thus, there has been a shift from a uniform and almost invariable conception of rural space, as a paradigmatic spatial category, to the acknowledgment of its mutability, diversity and plurality.

Fresh attention to this type of territory has been further encouraged by the recognition of its potential to resolve some of the severe problems faced by cities, such as human and real-estate congestion, the presence of annoying activities and unwanted infrastructures, the demand for more space for leisure and access to the natural world and the constant need for large quantities of food and raw materials.

However, one aspect of the question remains unshakable; namely, the acceptance, almost always implicit, of the existence of an unquestionably rural specific identity and the explicit conviction that the characteristics and development of this identity are always influenced by the circumstances derived from, or even imposed by, nearby cities.

The urban-centric standpoint has long enjoyed absolute primacy in most studies of rural areas and, in many cases, this situation persists or has even intensified. This is one of the most constant and recurrent features in the different perspectives from which rural–urban territorial interactions have been approached. In other words, studies have focused on a one-way influence, that of how cities impact rural areas, ignoring the possibility of a reciprocal territorial influence. In these studies, a common, albeit obvious, argument is that the intensity of the rural–urban relationship is in direct relation to their physical and temporal proximity. Consequently, special attention is paid to the situation of peri-urban and rururban spaces and, in particular, to those located in functional metropolitan areas. This focus is apparent in the multiple words and concepts commonly employed in this respect in publications on rural spaces: counter-urbanisation, suburbanisation, peri-urbanisation, ex-urbanisation, urban/urbanised countryside, remote rural, etc.

In any case, there is a growing realisation and acknowledgment of an almost undeniable fact: that the distinctive features of rurality and urbanity are weakening; formerly sharp contrasts are becoming attenuated or even eliminated. Thus, some authors practically deny the existence of rurality, claiming it has been replaced by new forms of post-urban city space as a result of metastatic metropolitanisation.

In the opposite direction, research attention on the changes caused by urban impacts on the rural environment has also led to the emergence of new concepts, such as the paradigm of "new rurality", which has been used (with frequent discrepancies of nuance) to refer to the reconstructed forms of organisation and to the functional transformations taking place within spaces that, from a former rural identity, have evolved towards a different kind of rural area.

Analyses of the emergence of new forms of rurality usually highlight the reduced importance of agricultural activity; the fact of economic, social and cultural deagrarianisation; the diversification of activities; and, especially, the processes of tertiarisation of jobs performed by the rural population, in their place of residence or elsewhere, whether rural or urban. These factors, jointly, have produced an extraordinary increase in physical and labour mobility [221,222]. Moreover, this mobility has been heightened with the growing use of rural spaces for residential functions (with the side effect of decongesting cities), either through the construction of main homes for permanent use or as leisure and vacation residences for sporadic use; that is, as secondary homes.

On the other hand, this tendency is expressive of the fact that agriculture, which used to be the essential activity of rural spaces and was considered their hallmark of identity and the main subject of research until quite recently, currently receives almost testimonial attention in academic studies. This scientific indifference has two topics of exception: the reduced productive, economic and social weight of agricultural activities and the impact of deagrarianisation and changing patterns of rural employment. Another question related to rural activity that has attracted considerable interest is that of food security and sovereignty. Thus, many studies, diagnoses and proposals have been published in this respect, especially in certain overpopulated Asian countries where intense rural urbanisation has taken place, as in China. This issue is a subject of growing concern, heightened by the impact of conflicts, such as the Russian invasion of Ukraine and its consequences for territories that are of major importance to global agricultural production.

Based on the much-debated and multifaceted concept of "new rurality", most studies in this field continue to focus on demographic and sociological aspects (such as population dynamics and the transformation of biological structures), rural and local development, changes in economic activities and land uses (in particular, the surge in service-sector activities for the tourism industry) and questions of landscape heritage and the effects of protecting natural spaces. Very recently, published studies have considered the possibility that rural spaces may alleviate the outcomes of major health crises, such as the COVID-19 pandemic, which tend to have more severe effects in urban spaces, which are more densely populated and, hence, more vulnerable to the spread of disease.

4. Proposals for Further Research

As has been pointed out, the above aspects are closely related to rural–urban interaction, and especially the impact of urbanisation and the urban reality on rural spaces. In view of these considerations, we propose the following lines of research.

1. Reflections on the epistemological foundation and the usefulness of territorial typologies as opposed to analysing the functionality of agrarian-related activities within a specific place. In this regard, and in accordance with [9] (p. 352), the authors of which observed that, "Given that situational contexts of the rural vary across the globe, as well as within individual countries, and that different rurality definitions have different purposes, it is widely acknowledged that there is no single index, set of factors, or scale", we suggest the following epistemological perspectives:
    - 1.1. This "situational context" can be analysed by using the epistemology of regional geographic analysis, applying the paradigm of the construction of geographic spaces and considering questions such as the medium- and long-term processes underlying the creation of agrarian structures (including the size of the property, the exploitation regime applied, the intended purpose and the spatial distribution of uses in relation to the agronomic potential) and the functional relationships with urban areas, in terms both of production and of the human population (for example, the relationship between place of residence and place of work or the way in which the supply radius of food products is determined).
    - 1.2. Time frame. In view of the above literature review, we believe the following sequence of actions would be appropriate:
        - (a) Identify the starting point of the change produced by the rural exodus;
        - (b) Determine whether the 1973 crisis affected mature industrial spaces;
        - (c) Identify the onset of i) dispersed urbanisation and ii) the intensification of tertiarisation, both of which are linked to post-industrial capitalism;
        - (d) Highlight recent changes arising from the Real Estate Bubble Crisis and the Great Recession and the exit processes from these events.

1.3. Scale. Prior reflection on this question is needed to determine the necessary focus of analysis and the specific characteristics of the settlement systems in each of the territories concerned. Although Johansen's approach ([203], p. 782)—namely, "the size of the rural unit had, as a starting point, that the size should be sufficient to capture local identity and culture"—is suitable as a starting point for strengthening rural communities, taking into account concepts such as local development and the scale of experience, research that is focused on supply functions might wish to address, specifically, the determination of an appropriate scale.

1.4. Precise knowledge about the multifunctionality of rural spaces. Do we seek to differentiate rural and urban areas or is our aim to establish gradients between them? Moreover, what are the means and forms of subsistence in the territories that combine rural and urban characteristics, at a certain scale? These questions may usefully be addressed by combining statistical sources on population parameters, land use and construction typologies. In this sense, it would be useful to:

(a) Strengthen and diversify the variables that reflect rural–urban interactions in terms of agrarian functionality. In this regard, Johansen's approach [203], focused on the function of "contact with nature", and the gradient of the extent of green spaces within the rural environment could support the proposal that studies of the rural–urban interaction should include variables enabling the measurement of land use on an agrarian-density gradient, ranging from natural protected to natural unprotected and productive, together with a classification of urban uses. In addition, we propose that big data should be used to measure the flows of agricultural products, at different scales, in order to determine the relationship between their distribution and the population of urban areas.

(b) Diversify the statistics used to characterise the demographic situation. The use of real growth should be complemented with the growth of its natural or spatial components, which are fundamental to the proper interpretation of indices of youth and aging.

(c) Consider the relationship between population range and economic activity regarding both the employed resident population and the productive establishments. This would be a valuable area of analysis as an identifier of rural–urban interaction: the location of industrial or tertiary activities in small population centres should not be masked by the concept of their corresponding population range but should be identified and considered as a manifestation of rural–urban interaction.

(d) Obtain more precise knowledge about rural residentialism and identify its functions: the separation of workplace–place of residence as a form of decongestion (with the use of larger and generally cheaper housing); as a means of access to leisure and recreation facilities and of proximity to the natural world; as part of the process of conserving rural settlement and life by the neo-rural population and by temporary residents returning to their territorial and socio-cultural roots; and as second homes and tourist accommodation.

(e) Specify the positive and negative effects of the installation of activities and facilities that are rejected by cities but necessary for their survival. These activities may require large spaces, putting the sustainability of rural spaces at risk and threatening heritage, environmental and landscape values, but at the same time they provide employment to the rural population. Greater awareness of these conflicting factors would facilitate the formulation of models describing an optimal response to the situation.

2. A reflection on the possibility of a "self-fulfilling prophecy" arising from the identification of rural areas as places where agricultural activity is associated with unemployment, poor access to services and an aging population, whilst overlooking other values such as the quality of life enjoyed (in terms of tranquillity and environmental conditions, etc.), a factor that is emphasised in campaigns to promote rural tourism. The emphasis often placed on the negative image of the rural environment contributes to the lack of self-esteem among the population, thus fostering processes of depopulation.
3. The incorporation of big data as an alternative, universal and accessible source of information for studying the flows of people and goods aforesaid. Greater use should be made of remote image data to map short-term changes in land use.

Author Contributions: Conceptualization and references, C.D.-V.; methodology, M.-L.G.-M.; writing—original draft preparation, C.D.-V. and M.-L.G.-M.; writing—review and editing, C.D.-V. and M.-L.G.-M.; supervision C.D.-V. and M.-L.G.-M. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

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

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Article

Access to Land for Agricultural Entrepreneurial Activities in the Context of Sustainable Food Production in Borgou, according to Land Law in Benin

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Abstract: Access to land is crucial for food systems to address the challenges caused by habitat and biodiversity loss, land and water degradation, and greenhouse gas emissions. Sustainable food production requires land security upstream for agricultural production. Land security emanates from the land law implemented in-country by government policy. In the span of a decade (2007–2017), three different land reforms have been adopted in Benin. This paper aims to investigate the land rights and land tenure security for sustainable food production according to land law and the factors that influence agricultural entrepreneurial activities in North Benin. The study was carried out in the Borgou department, mainly in five communes that are beneficiaries of the Responsible Land Policy Project of GIZ (Promotion d'une Politique Foncière Responsible: ProPFR/GIZ). A multistage sampling procedure was used to select the agricultural entrepreneur respondents. A total of 102 agriculture entrepreneurs were interviewed in 25 villages. According to land law in Benin, the results highlight the different levels of land tenure security and land rights represented by types of land documents: type contract (use right), certificates of customary ownership (ADC), and land title. The research reveals that 44.3% of the land of agriculture entrepreneurs' respondents possessed the certificates of customary ownership and 18% possessed the land title. The facilitation of access to legal land documents such as certificates of customary ownership and land titles can protect agricultural entrepreneurship for sustainable food production.

Keywords: land access; agricultural entrepreneurship; land law; sustainable production; Benin

Citation: Akowedaho, B.D.; Guinin Asso, I.; O'heix, B.C.P.; Adéchian, S.A.; Baco, M.N. Access to Land for Agricultural Entrepreneurial Activities in the Context of Sustainable Food Production in Borgou, according to Land Law in Benin. *Land* **2022**, *11*, 1381. https://doi.org/10.3390/land11091381

Academic Editors: Carmen Delgado Viñas and María L. Gómez-Moreno

Received: 30 June 2022
Accepted: 10 August 2022
Published: 23 August 2022

1. Introduction

In Africa, agriculture and food systems are an important provider of employment and livelihoods [1]. The global food system may be facing serious problems, but many powerful actors are hard at work to address the challenge without too disruptive a change [2]. Food systems across the world have caused habitat and biodiversity loss, land and water degradation, and greenhouse gas emissions [3]. Land use for food production is a key component of land systems and a central part of food systems at the interface between actors that provide inputs in food systems and those that process and consume food [4]. The intersections between land and food systems are key to many global environmental changes, environmental justice, and sustainability challenges [4]. Access to land is crucial to the improvement of agricultural performance, food security, and economic development [5,6]. Land access is defined by the land tenure system of each country. The land tenure system can be defined as the rights and institutions that govern access to and use of land [7]. The tenure system of land involves a system of rights, duties, and responsibilities concerning the use, transfer, alienation, and ownership security of land and its resources [8].

The Republic of Benin is a former colony of France which gained independence in 1960. Benin became, in 1991, a democratic republic. Like some countries in Sub-Saharan Africa, the land system of Benin has undergone modification of proprietary rights. Since 1991, the land system has been characterized by diverse actors, including traditional community leaders, families, lawyers, and the government, which implemented dual laws (customary law and modern law). This situation creates insecurity in agricultural entrepreneurial activities, which negatively influences agriculture investment for food production. The land policy reforms were initiated by different governments and legislation. The last land policy reform was the legal foundation of the land administration in Benin. This is the 2013 Land Administration Law [9] that, together with the 2017 addendum [10], replaced different previous land laws (Table 1). The new land law encompasses, from art. 347 to art. 378, the customary and rural land rights and the justice and administrative functions of rural land management [9].

Table 1. Chronological evolution of land policies in Benin Republic after 1990.

Important Dates	Type of Legislation	Description of Consecutive Legislations
1990	Constitution	N° 65-25: Review of the land ownership of the Constitutional Marxist military regime established in 1972
February 2007	Post-colonial land	Rural land law established
14 August 2013	Laws	Land law N° 2013-01 established
15 August 2017	New laws modifying land law N° 2013-01	Land law N° 2017-15 established

The execution of the land administration in Benin is assigned to the National Land Registry and Agency (*Agence Nationale du Domaine et du Foncier*: *ANDF)*. The Land Administration Law and the *ANDF* have the objective of centralizing land administration and recording the entire national territory in one digital central land administration system. Generally, land tenure reform has made a great contribution to improving agricultural productivity and can provide an effective long-term solution to food security [11]. The condition of access to land is crucial for agricultural entrepreneurial activities. The demands, opportunities, and challenges of the changing business environment in the agricultural industry have required farmers to become entrepreneurial [12]. However, investment for food production through agricultural entrepreneurial activities depends on the land tenure security. The authors of [13] found that, although the links between tenure security and agricultural productivity are of primary interest, tenure security is endogenous, and a positive correlation between investment and land tenure security could occur because people invest to become more tenure secure. According to [14], individual and secure land tenure rights are vital components of a productive agricultural sector, which is crucial to poverty alleviation and economic growth. Entrepreneurship is one of the determinants of economic growth [15], and the creation of small and medium-sized enterprises, especially in the secondary and tertiary sectors, can resolve problems induced by the changes in agriculture [16]. In developing countries such as Benin, land issues are of crucial importance due to the significant incidence of agriculture on economic growth [17], and agricultural entrepreneurial growth impacts poverty significantly [18]. The importance of entrepreneurship in agriculture means that interest in this field of research has only gained more interest recently and is still being consolidated [19]. This article aims to analyze the land rights and the land tenure security for agricultural and entrepreneurial activity according to the new land law in Benin. Furthermore, the types of land documents provide by the land law in Benin are examined according to the land rights and the level of land tenure security [20] in one part, and according to the factors influencing agricultural entrepreneurial activities in the other.

2. Methods and Materials

2.1. Method for Collecting and Analyzing Data

2.1.1. Study Area

The study was carried out in the Borgou department (Figure 1). Located in northern Benin, the territory covering the department of Borgou is 25,856 km^2 with 1,214,249 inhabitants [21], which represents 46% of Benin's surface area, and is situated between latitude 8°45′ and 12°30′ N and between longitude 2° and 3°15′ E. This region is characterized by a Sudano-Guinean climate with a rainy, relatively cold season from April to October and a dry, very hot season from November to March. Annual rainfall varies from 900 to 1200 mm, and extreme average temperatures are 30.8 °C in February (dry season) and 24.4 °C in August (rainy season). The department has a total of eight communes, of which five communes represent this study area: Bembèrèkè, Kalalé, N'Dali, Sinendé, and Tchaourou.

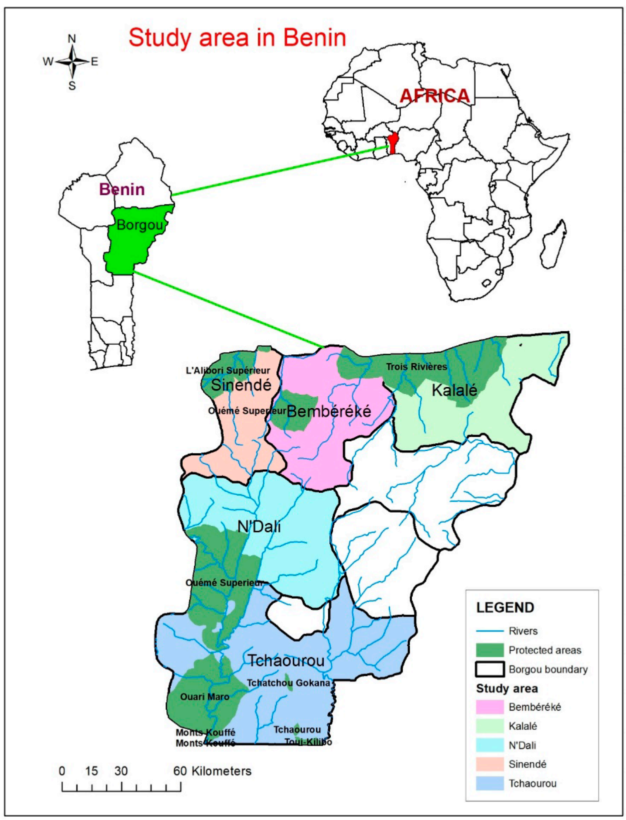

Figure 1. Study area.

2.1.2. Data and Sampling Procedure

The data used in this study come from the secondary data, i.e., the Land and Domain Code law (Code Foncier et Domanial) reviews in 2017, and the primary data collected through the empirical survey. Land tenure security refers to the actual control of land [22]. It mainly depends on "the extent to which legal rules are effectively enforced at the local level" [23]. The legal rules are defined in the Land and Domain Code, which is the secondary database to analyze the different levels of land security for agricultural entrepreneurial activities through the possessing of land papers.

The empirical survey was focused on the types of land documents possessed by the agriculture entrepreneurs and their land tenure security following the domain and code land law in Benin. The survey also examines the outputs of agricultural entrepreneurial activities (activity sector, land harness, job creation, etc.), as well as the factors influencing this activity. It was carried out in November 2020 with the collaboration of the GIZ institution.

A multistage sampling procedure was used to select the agricultural entrepreneur's interviews. In the first stage, the communes of N'Dali, Bembèrèkè, Sinendé, Tchaourou, and Kalalé were purposively selected as the five communes that are beneficiaries of the Responsible Land Policy Project of GIZ (Promotion d'une Politique Foncière Responsible: ProPFR/GIZ). This project aims to improve the institutional framework and processes for securing land use and ownership rights in the department of Borgou [24]. Second, we asked the GIZ officer to provide us with a list of villages in their locations. From the lists, we randomly selected five villages per commune. Therefore, a total of 25 villages were selected. Third, we acquired the lists of the agricultural entrepreneurs in all the selected villages and applied a proportional random sampling (average 20 agricultural entrepreneurs per commune) procedure to select individual farmers to be interviewed. A total of 102 agricultural entrepreneurs were interviewed in the five communes (Table 2).

Table 2. Study area and sampling.

Communes	Villages	Sample Size
N'Dali	Tamarou, N'Dali centre, Sirarou, Mareborou, Boko	21
Bembèrèkè	Gahmaré, Bembèrèkè, Gamia, Wanrarou, Ina	20
Sinendé	Siki-Fô-bouré, Guessou-bani, Niaro-Gouou, FômBouko, Sékéré-Soka	20
Tchaourou	Tchaourou centre, Guinerou, Chala-Boyadi, Akoudanmon, Tekparou	20
Kalalé	Kidaroukperou, Kalalé-Nassiconzi, Nassimina, Peonga, Suanin-Dunkassa	21
Total		**102**

2.1.3. Data Collection and Analysis

In order to achieve the objective of this study, descriptive statistics, such as frequency counts, simple percentages, means, and tables, were used to analyze the results. They were all exported into the International Business Machines (IBM) Statistical Package for Social Scientists (SPSS) version 20 data editor for a one-sample *t*-test.

However, agricultural entrepreneurial activity is a complex issue, as the farmer can be an owner, a tenant, a manager, a subcontractor, or a combination, suggesting that the methods used to analyze business entrepreneurs in other sectors may not be easily transferred to an analysis of agricultural entrepreneurial activity. Therefore, the *t*-test revealed the significance of the factors through the null hypothesis (H0) and alternative hypothesis (H1). The factors that can influence the agricultural entrepreneurial activity identified in this study are land access mode factors (occupation, heritage, donation, and sharecropping) and socioeconomic factors (financial support from parents or friends, land availability, experience in the agriculture sector, microfinance or bank loans, autonomy decisions, and profitability of activity).

2.2. Agriculture Entrepreneurial Activity

Agriculture is basically the set of practices through which people produce food [25]. Agriculture is multifunctional and evolving [26,27]. Agricultural production cannot be separated from the other aspects of food systems, such as food supply chains, the food environment, and consumption [28,29]. The function of agriculture is not only the production of food; it has also shaped landscapes, preserved biodiversity, and created a cultural heritage over centuries [30]. However, defining farmers' entrepreneurial activity is complex as they do not operate in similar business activities characterized by their urban counterparts [31], because entrepreneurship in the agricultural sector encompasses all aspects of food systems (food supply chains), biodiversity, environment, consumption, and tourism. Entrepreneurship is the process through which opportunities to create future goods and services are discovered, evaluated, and exploited [32]. Entrepreneurial options that farmers have employed include implementing selective product specialization, enterprise diversification, market orientation, production upscaling, product development, process innovation, and vertical integration [33]. Agriculture production and related activities (food processing, biodiversity, environmental protection, consumption, and tourism) serve as the foundation for agricultural entrepreneurial activities with the goal of creating added value. This encompasses the opportunities to create new goods and services or new value chains. For De Wolf, smallholder farming entrepreneurship includes the production of specialty food products for niche markets, the provision of services to other farmers, and the use of agricultural assets such as the farmhouse and the farm animals to attract paying visitors [34]. According to farm management studies, entrepreneurship by farmers promotes farm diversification [31,35]. Although farmers tend to establish a number of similar farm businesses, these businesses can still be seen as entrepreneurial because they require "contracts with new customers and/or suppliers, new marketing channels, and reorganization of the management in the business" [36] (p. 242). In this paper, agricultural entrepreneurial activities are defined as all activities based on the use of land to produce food for the market and preserve biodiversity.

2.3. Conceptual Framework

This article aims to position the concept of land tenure security in sustainable food production in Benin through agricultural entrepreneurial activities. Land investment in Africa is driven by the large amount of perceived available land and weak land rights [37], increased demand and prices for food, energy systems transitions, biodiversity conservation, climate change responses, geopolitics, and development strategies [38]. The land conflict affects land investment, which weakens agricultural entrepreneurial activities and sustainable food production. Land conflict is a result of deficiencies in arbitration mechanisms in contexts of plurality of norms [39] and competition between authorities [40], not just of increasing pressure on land. It also highlights the interest that powerful actors have in managing confusion [41], in urban and peri-urban environments [42], as well as in rural areas. Rural land is coming under multiple pressures which include population growth and increasing fragmentation, land-use conversion, commercial investments, environmental degradation due to drought, soil erosion, and nutrient depletion, as well as natural disasters and conflicts [20]. The degree of implementation of the reforms is even more crucial.

Benin's case is particularly interesting in this regard because the land debate began in the 1990s, and Benin implemented three different land reforms in the span of a decade (2007–2017). The last land reform (2017) aims to centralize land administration, with the objective of recording the entire national territory in one centralized digital cadaster ("*le cadastre national numérique*"). Land is an essential resource for agriculture and entrepreneurial activities. Access to land is a fundamental basis for human shelter, food production, and other economic activity, including by businesses and natural resource users of all kinds [20]. Therefore, the modes of access to the agricultural land in Benin (lease, purchase, testamentary succession, and inter vivo donation) were inscribed in land and domain code law (art. 360, 2013). Reviewed in 2017, the domain and code of land law specified that each village and each municipality must have a land administration committee (Land and Domain Code: art.428, 2017). However, the land tenure security for agricultural entrepreneurial activities involves some stakeholders, which facilitate the process of accessing the agricultural land. According to the land law in Benin, the stakeholders identified are land policy, institutions of law, local authorities, informal customary, and partners such as nongovernmental organizations (NGOs), professional organizations (POs), and private sectors. Sustainable food production starts with land tenure security (an essential resource) and food market availability, which contribute to food security, job creation, and cash flow (Figure 2).

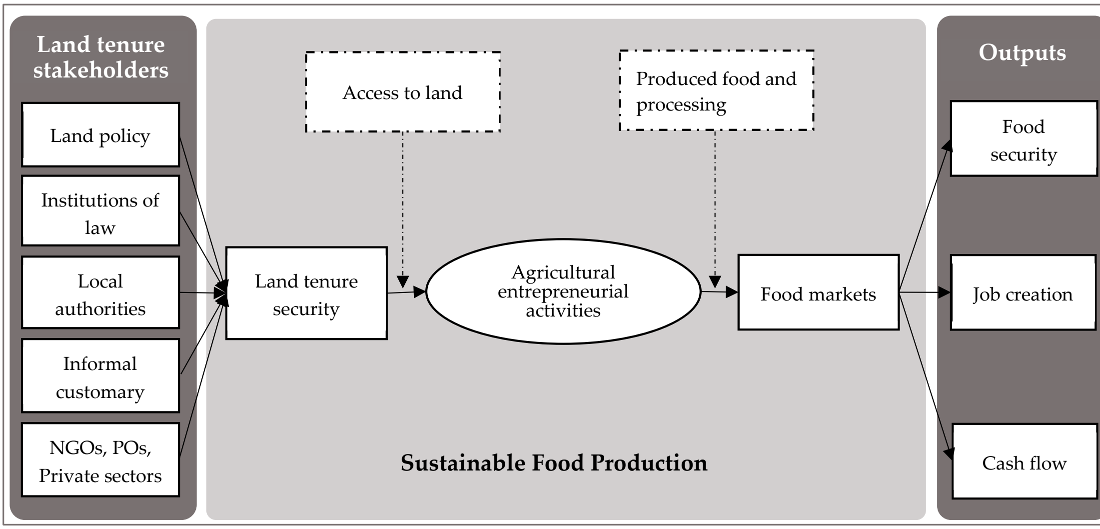

Figure 2. Conceptual framework.

3. Results and Discussion

3.1. Land Rights and Land Tenure Security for Agricultural Entrepreneurship, according to Domain and Code Land Law in Benin

Accessing land for agriculture activities is defined by the recent land reform that was enacted by the 2013 Code Foncier et Domanial (Domain and Code of Land law) reviews in 2017. According to the domain and code of land law (art.360) in Benin country, "*the permanent transfer of rural customary land may be by purchase, intestate or testamentary succession, inter vivo donation, or by any other effect of obligation ... This contract must be based on the rural land title corresponding to the plot of land concerned, provided that the village in which it is located and which has been the subject of the establishment of a rural land tenure plan as provided for by this code*". Land is a veritable ingredient in agricultural entrepreneurial activities. The formalization of land rights for exerting agriculture activities in order to secure production necessitates a process which encompasses the landowners, as well as local and national authorities. The informal institution (the landowner's family) and the formal institution (local and national governance institutions) are both involved in this process. Actual tenure security, which could be derived from both formal and informal institutions, is based on tenure holders' "actual control of property, regardless of the legal status in which it is held" [22]. The informal institution is governed by customary law, which is recognized in the domain and code of land law of Benin (art. 351). This does not guarantee the security of land but constitutes the first step toward formalizing the land rights. However, agricultural activities may be carried out on land subject to customary regulation. When the customary regulation is in writing, the name of the contract type is taken (art. 354). This contract (mortgage, rents, pledges ...) must be registered in the village section of land tenure, with a copy to the commune's land management commission and the local office responsible for confirming land rights. The contract type for at least 10 years can be disrupted at any moment with several motifs, e.g., if the tenant violated the contractual clauses or repossession of the land by the owner with a view to exploitation.

The formalization land can provide the certificate of customary ownership (Attestation de Détention Coutumière: ADC). The obtention of this certificate is defined in the domain and code of land law in Benin (art. 352) by applying for ADC to the mayor of the commune. The mayor with the support of village section of land management (Section Village de gestion foncière) then proceeds to the contradictory public survey.

The record of the survey is transmitted to the mayor who, with favorable opinion of the neighborhood, establishes five copies of the ADC distributed as follows: one for the commune commission land management, one for the village section of land management, one for the land domain office, and one for the requestor.

This certificate of customary ownership can be contested by following the same process. According to the domain and code of land law, art. 386 to art. 393, the land conflict can be managed in a friendly manner or in front of the mayor. The land title confirms the ownership of land according to art. 376 of the law of the land and domain code in Benin. It is the uncontested right of the landowner (high-level land security).

According to the domain and code of land law, the land rights can be classified from informal to formal. The typology of land rights [20] along the horizontal axis is correlated with the types of land document in Benin. This typology of land rights (the land rights continuum) indicates the land value attributed by land law. The formality of land rights according to the type of land document shows the different level of land tenure security in the vertical axis of the proposed model.

One of the main uses of the continuum of land rights model is to understand relationships between land rights and land tenure security, with a focus on improving land tenure security, especially for the poor [43]. The land document types reflect the different levels of land tenure security. This land security is proposed on the vertical axis through the variables of legitimacy (acknowledgement by people) and legality (legislation is linked to policy).

Figure 3 depicts the land rights and the land tenure security for agricultural activities according to the domain and code of land law in Benin.

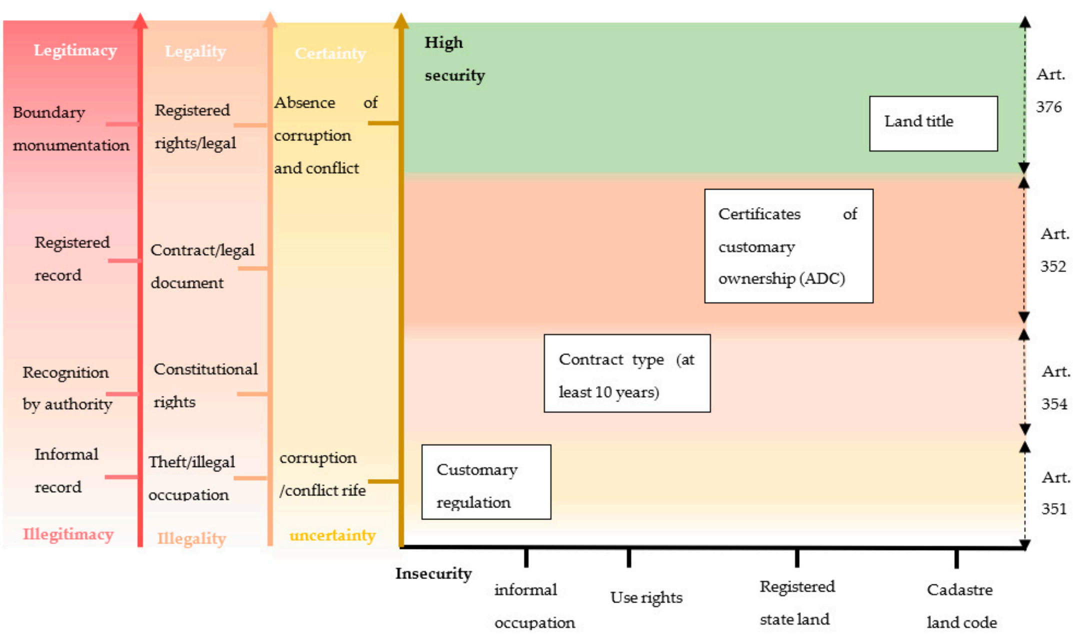

Figure 3. Land rights and land tenure security according to the domain and code of land law.

This diagram shows the different levels of land tenure security and the land rights for agriculture activities according to the types of land document possessed.

According to UN-Habitat (2018), tenure security still tends to be strictly defined in more statutory forms of legal documentation, such as individual land titles. However, the customary regulations recognized by the domain and code of land law (art. 354) do not guarantee the security of land for agricultural entrepreneurial activities. Since colonial times, customary land tenure was not thought to provide adequate tenure security, thereby discouraging investment and negatively affecting agricultural productivity [44,45]. The customary land tenure corresponds to the illegal occupation where there are the most conflicts and corruption. The contract type (art. 354) is recognized by authorities (legitimacy axe) and grants use rights to agriculture entrepreneurs. The certificate of customary ownership (art. 352) reflects the registered state land for the land rights. This land document provides agriculture entrepreneurship through the legal title and registered record for the land tenure security. The land title (art. 376) indicates the absence of corruption and conflicts. It is a high level of land tenure security that corresponds to agricultural entrepreneurship and security investment for sustainable food production.

3.2. Different Types of Land Documents Possessed by Agriculture Entrepreneurs

In Benin, land reform defined the process of formalizing agricultural land in order to achieve total land tenure security. This process, which involves the local, communal, and governmental authorities, requires financial resources from agriculture entrepreneurs. Certificates of customary ownership (ADC) range between 30,000 and 50,000 FCFA (47.55 and 79.25 USD) (1 USD = 630.853 FCFA on 15 May 2022), depending on the size of the plot. According to some authors, this is above the financial capacity of the farmers and will make it difficult for the rural people to access ADC [46]. The process of getting the land title at the National Land Registry and Agency depends on the communes and the size of the plot. According to [46], the cost for citizens is doubly limited. First, surveyors freely fix the cost of demarcation, which is one of the major costs of the procedure, and frequently exceeds 300,000 FCFA (475.55 USD). Second, the registration procedure follows several others (purchase, having a certificate, etc.), and the full cost for users must include those steps, as well as other indirect expenses (travel to the office, etc.). The cost of land titles remains high; however, above all, demarcation fees are unregulated and, therefore, freely fixed by surveyors. The introduction of notaries as a mandatory step for transfers incurs significant upstream costs: a notarial sales contract or a minute registration costs around 300,000 FCFA (475.55 USD). Following the different costs for land paper in the Borgou department, the percentage of land paper per commune is depicted in Figure 4.

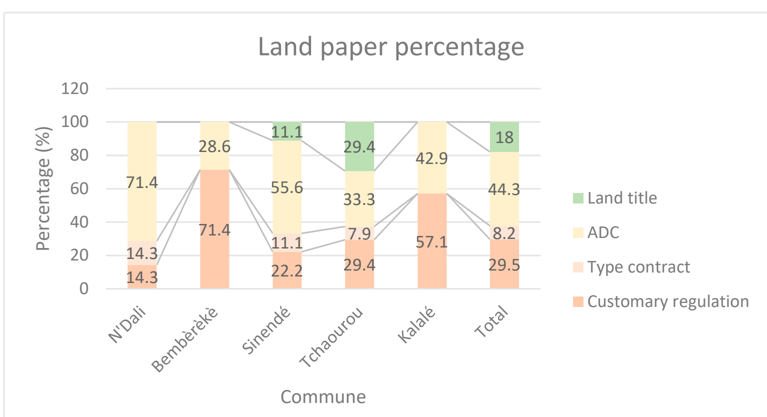

Figure 4. Types of land documents.

According to the domain and code of land law, 62.3% of the land of agriculture entrepreneurs' respondents was secure (44.3% possessed the certificates of customary ownership (ADC) and 18% possessed the land title). Land registration for ADC requires a survey with the landowner, the neighbors, local authorities (customary authorities, chief of village), and topographical markers, which makes the processing time long. However, this process of getting an ADC is organized by village or by zone, which facilitates the availability of all actors at the moment, according to the respondents. Amongst the five communes of the study, the number of agriculture entrepreneurs who possessed the land title in the communes of Tchaourou and Sinendé was 29.4% and 11.1%, respectively. More than 50% of agriculture entrepreneurs in the commune of Bembèrèkè and Kalalé still follow customary regulations such as land documents. More than 90% of the rural population in Sub-Saharan Africa (of which 370 million people are considered to be poor) accesses land a via legally insecure customary and informal tenure systems [47]. This shows the land insecurity for the agriculture entrepreneurs in both communes.

3.3. The Sociodemographics of the Agricultural Entrepreneurs

The findings from descriptive statistics provide insight into the sociodemographic characteristics of agricultural entrepreneurs' respondents. These sociodemographic characteristics of agricultural entrepreneurs group sex, education background, and experience. Table 3 provides the frequency and percentage of agricultural entrepreneur respondents.

Table 3. Agricultural entrepreneur profiles.

Characteristics		**Communes**					**Total**
		Bembèrèkè	**Kalalé**	**N'Dali**	**Sinendé**	**Tchaourou**	
		N%	***N%***	***N%***	***N%***	***N%***	***N%***
Sex	Female	10.0	19.0	23.8	4.8	5.3	11.8
	Male	90.0	81.0	76.2	95.2	94.7	88.2
Education background	Illiterate	30.0	9.5	52.4	9.5	0.0	20.6
	Primary	15.0	23.8	4.8	42.9	52.6	27.5
	Secondary	30.0	47.6	28.6	47.6	42.1	39.2
	University	25.0	19.0	14.3	0.0	5.3	12.7
Ethnic groups	Bariba	95.2	75.0	95.2	0.0	19.0	57.8
	Peulh	0.0	15.0	0.0	0.0	23.8	7.8
	Lokpa	0.0	0.0	0.0	5.3	0.0	1.0
	Nago	0.0	0.0	4.8	89.5	57.1	29.2
	Others	4.8	10.0	0.0	5.3	0.0	3.9
		Mean	Mean	Mean	Mean	Mean	Mean
Age		48.05 (±11.82)	41.48 (±5.68)	48.19 (±10.05)	42.62 (±10.46)	46.89 (±9.26)	45.39 (±9.90)
Experience		14.80 (±10.68)	15.24 (±4.52)	9.33 (±4.26)	10.71 (±6.06)	13.5 (±5.42)	12.70 (±6.86)

The profile of each respondent is a summary of general demographics for the entire sample. The majority of agricultural entrepreneurs (88.2%) were men. Almost 20.6% of agricultural entrepreneur respondents did not have an educational background (illiterate), 27.5% had completed the primary level, in contrast to secondary school (39.2%). The average age of agricultural entrepreneurs was 45.39 (±9.90) years. The mean agricultural entrepreneur experience was 12.70 (±6.86) years.

3.4. Different Sectors of Agricultural Entrepreneurial Activities

Agricultural entrepreneurial activities embrace all sectors of agriculture production and non-agriculture production. This research focuses on agricultural entrepreneurs who have land issues and are registered in the GIZ database. Table 4 shows the percentage of entrepreneurs by agricultural entrepreneurial activity sector.

Table 4. Sectors of agricultural entrepreneurial activities.

Sectors		Communes					Total
		N'Dali	Bembèrèkè	Sinendé	Tchaourou	Kalalé	
		N%	*N*%	*N*%	*N*%	*N*%	*N*%
Vegetal production (annual crops)	Female	23.8	0.0	4.8	5.3	30.0	11.8
	Male	76.2	100.0	95.2	94.7	70.0	88.2
Vegetal production (perennial crops)	Female	20.0	0.0	0.0	6.2	11.8	11.8
	Male	80.0	100.0	100.0	93.8	88.2	88.2
Livestock	Female	25.0	0.0	0.0	5.9	7.7	11.8
	Male	75.0	100.0	100.0	94.1	92.3	88.2
Crop processing	Female	0.0	25.0	100.0	0.0	60.0	11.8
	Male	100.0	75.0	0.0	0.0	40.0	88.2

Four sectors were identified as agricultural entrepreneurial activities in the area under study: vegetal production (annual crops), vegetal production (perennial crops), livestock, and agri-food transformation. In the Borgou department, the agricultural entrepreneurial activities are conducted by women, as well as men. The results show that, although 11.8% of agricultural entrepreneurs were women, in the communes of Bémbèrèkè and Sinendé, agricultural entrepreneurial activities such as vegetal production (perennial crops) and livestock were still completely performed by men. In the communes of N'Dali and Kalalé, women featured in entrepreneurship linked to vegetal production (annual crop), with 23.8% and 30.0%, respectively. Crop processing was an agricultural entrepreneurial activity performed only by women (100%) in the commune of Sinendé, as well as by the majority in the commune of Kalalé (60.0%). Women had more opportunities for crop processing in both communes than for other agricultural entrepreneurship activities. Benin's customary law, however, does not allow succession to land for women, and this limits women's ability to invest in agricultural entrepreneurship with insecure land. In Tchaourou, no agricultural entrepreneurs are involved in crop processing.

3.5. Agricultural Entrepreneurs' Average Land Use and Employment

In the context of agricultural entrepreneurial activities, the acreage of land used and the number of jobs created are important indicators. These indicators give an overview of the size and scope of the agricultural enterprise. Table 5 highlights the average land area and the average number of employees with their standard deviation.

Table 5. Average land area and number of employees.

Indicators (Average)	Commune					Total
	N'Dali	Bembèrèkè	Sinendé	Tchaourou	Kalalé	
Land available (ha)	15.55 (±13.90)	16.42 (±15.00)	29.48 (±16.53)	14.26 (±14.36)	12.57 (±9.85)	17.74 (±15.117)
Land harnessed (ha)	13.02 (±13.32)	16.42 (±15.07)	20.33 (±13.94)	9.84 (±9.73)	12.33 (±10.00)	14.41 (±12.89)
Land secured (ha)	11.67 (±10.97)	12.35 (±18.02)	8.83 (±6.77)	11.73 (±10.54)	10.24 (±12.68)	11.16 (±12.296)
Permanent employees (male)	4.48 (±4.29)	2.75 (±5.69)	4.76 (±3.66)	3.84 (±2.73)	3.67 (±2.35)	3.91 (±3.192)
Permanent employees (female)	2.33 (±1.77)	1.55 (±3.02)	0.24 (±0.59)	1.79 (±1.55)	2 (±1.90)	1.58 (±2.02)
Occasional employees (male)	2.76 (±2.21)	13.2 (±17.38)	1.71 (±60)	1.32 (±2.02)	4.67 (±5.10)	4.72 (±9.17)
Occasional employees (female)	2.19 (±2.098)	12.2 (±17.27)	9.57 (±8.48)	2.79 (±1.93)	1.62 (±2.01)	5.67 (±9.58)

We identified three categories of land use: land available, land harnessed, and land secured. In the five communes of the department of Borgou, i.e., the study area, the average amount of land available for agricultural entrepreneurial activities was 17.74 (±15.117) ha. Of this land available, 14.41 (±12.89) ha was harnessed for agricultural entrepreneurial activities, representing 81.22% of the land available. The land available is the land registered by the customary regulations as land rights. According to UN-Habitats (2008), this land is allocated by customary authorities and is espoused for conflict. This proportion is above that of the Borgou department, where the proportion of land harnessed per hectare of land available is 53.9% [48]. Furthermore, 62.90% of the land available is secured (11.16 ha (± 12.296)) through possession of the land paper (ADC or land title). Permanent and seasonal employment is available on the farms of agricultural entrepreneurs. The number of employees differs according to sex. The number of permanent male employees on the farms of agriculture entrepreneur respondents varied from three to five, and the number of women varies from one to two. According to the period and extent of activity on the farm, the number of occasional employees (men) ranged from one to 13, and that of women ranged from two to 12.

3.6. The Effects of Accessing Land Mode Factors on Agricultural Entrepreneurial Activities

In this section, we address the effects of accessing land mode factors on agricultural entrepreneurial activities in rural areas, which raise the following hypotheses:

H0: *Sociodemographic and land access mode factors have no significant effect on agricultural entrepreneurial activities.*

H1: *Sociodemographic and land access mode factors have a significant effect on agricultural entrepreneurial activities.*

The sociodemographic factors identified that can influence agricultural entrepreneurial activities in this study were gender, age, and education level, while the land access mode factors were occupation, heritage, donation, and sharecropping (Table 6).

Table 6. The *t*-test of the effect of land access mode factors on agricultural entrepreneurial activities.

Variables/Factors	*t*	df	Sig.
Gender	27.523	101	0.000 *
Age	46.327	101	0.000 *
Education level	25.673	101	0.000 *
Occupation	3.126	101	0.002 *
Heritage	20.349	101	0.000 *
Donation	3.494	101	0.001 *
Sharecropping	1.749	101	0.083

* $p \leq 0.05$.

The results show that the *t*-test value for gender was 27.523 while that of age was 46.327, and that of education level was 25.673. However, looking at the Sig. (two-tailed) column, it can be seen that the values of gender, age, and education level were all 0.000, i.e., lower than the standard significance level of 0.05, indicating that the null hypothesis was rejected. As a result, with a 95% confidence level, we can say that gender has a significant effect on agricultural entrepreneurial activities. This significant effect of gender on agricultural entrepreneurial activities is corroborated by the fact that 70% of women are engaged in agriculture (World Bank, 2016), and women are actively involved in food systems in several fundamental functions, i.e., growing and managing crops, livestock, agribusinesses, and food retailing, as well as preparing food for their families [3]. In the department of Borgou, this is also reflected in the descriptive statistics, with a relatively large proportion of our female respondents (11.8% of all female respondents) reporting the intention to be self-employed (Table 3). This result corresponds with modern trends suggesting that entrepreneurship has become more popular among women (see, e.g., [49–51]). Women are credited with playing leading roles in facilitating the introduction of new practices and conceptions on the farm, thus acting as important innovators [52–54]. The average age of agricultural entrepreneurs was 45.39 (±9.90) years (t = 46.327; Sig. (two-tailed) = 0.000). This confirms the result of [55], which revealed that farm growth probability was highest for farmers aged 40–49 years. However, for [56], the taxonomy of entrepreneurial farmers indicated that the "farmer as entrepreneur" was usually younger than 45 years of age. In terms of decline and exit, it has been proven that the younger age group is associated with a lower probability of the business declining and exiting the sector [55,57,58], as younger farmers tend to have more capacity to grow the farm size than older farmers do [59]. The education level had a significant effect on agricultural entrepreneurial activities (t = 25.673; Sig. (two-tailed) = 0.000). The education level can cause an ambiguous overall effect; while a higher level of education might benefit the farm's development, well-educated farmers have better job opportunities outside of the farm, which could possibly lead to a reduction in farming activities [60].

As can be seen, the t-test value for occupation was 3.126, while that for heritage was 20.349; these values were 3.494 for donation and 1.749 for sharecropping. However, looking at the Sig. (two-tailed) column, it can be seen that the values for occupation, heritage, and donation were respectively 0.002, 0.000, and 0.002, i.e., lower than the standard significance level of 0.05, indicating that the null hypothesis was rejected. As a result, at a 95% confidence level, we can say that respondents' land access mode factors (occupation, heritage, and donation) have a significant effect on agricultural entrepreneurial activities. The t-test value for sharecropping was 1.749 with a Sig. (two-tailed) of 0.083. Hence, since the Sig. value was greater 0.05, the null hypothesis was hereby accepted. Accordingly, sharecropping did not have a significant effect on agricultural entrepreneurial activities. Agricultural entrepreneurial activities are considered agriculture investments; thus, the land factors influence agricultural entrepreneurial decisions. According to [61], in Benin, land certification has improved tenure security and stimulated investment in agriculture. Land registration, it is argued, increases credit use through greater incentives for investment in agriculture and reduces incidences of land disputes [62,63]. The resulting legal tenure also influences investments in fixed inputs such as machinery, which are important for enhancing productivity [64].

3.7. The Effects of Socioeconomic Factors on Agricultural Entrepreneurial Activities

Agricultural entrepreneurial activities encompass all aspects of food systems (food supply chains, biodiversity, the environment, and consumption). According to [16], rurality and the entrepreneurial process form a dense, complex, and dynamic network of mutual influences. The socioeconomic factors identified in this study included financial support from parents or friends, land availability, experience in the agriculture sector, microfinance or bank loans, autonomy decisions, profitability of activity, and farm government policy (Table 7). The effects of socioeconomic factors on agricultural entrepreneurial activities in rural areas raised the following hypotheses:

H0: *Socioeconomic factors have no significant effect on agricultural entrepreneurial activities.*

H1: *Socioeconomic factors have a significant effect on agricultural entrepreneurial activities.*

Table 7. The t-test of the effect of socioeconomic factors on agricultural entrepreneurial activities.

Variables/Factors	t	df	Sig.
Financial support from parents or friends	4.335	101	0.000 *
Land availability	6.795	101	0.000 *
Agriculture experience	5.575	101	0.000 *
Loan from microfinance or bank	5.878	101	0.000 *
Autonomy decision	25.196	101	0.000 *
Activity profitability	27.523	101	0.000 *
Farm government policy	1.421	101	0.158

* $p \leq 0.05$.

The table shows that the t-test result for financial support from parents or friends was 4.335 while that for land availability was 36.885; these values were 5.575 for agricultural experience, 5.878 for loan from a microfinance or bank, 25.196 for autonomy decision, and 33.420 for activity profitability. However, looking at the Sig. (two-tailed) column, it can be seen that all values were 0.00, i.e., lower than the 0.05 confidence limit. Hence, the null hypothesis was hereby rejected, while the alternate hypothesis was accepted. As a result, with a 95% confidence level, we can say that the respondents' socioeconomic factors (financial support from parents or friends, land availability, experience in the agriculture sector, loan from microfinance or bank, autonomy decision, and profitability of activity) had a significant effect on agricultural entrepreneurial activities. According to the literature, family involvement in the business supports the decision to continue farming [57,65,66] and to expand the business [67]. Manolova et al. (2019) showed that family financial support helps the young entrepreneur overcome capital market voids [63]. The *t*-test value for farm government policy was 1.421 with a Sig. (two-tailed) equal to 0.158. Hence, since the Sig. value was greater than 0.05, the null hypothesis was hereby accepted. Accordingly, the farm government policy had a significant effect on agricultural entrepreneurial activities.

4. Conclusions and Recommendations

The land is an essential factor for agricultural entrepreneurial activities and sustainable food production. This study examined the land rights and the land tenure security according to the domain and code of land law in Benin. The different types of land documents ascribed in land law in Benin depict the land rights and the land tenure security following UN-Habitats. The results reveal that the land has customary regulations and is not secure land, reflecting illegal occupation, which results in the most conflicts and corruption. Customary regulation still serves as the land document for 29.5% of the land exploited by agricultural entrepreneurs. This represents the threat of sustainable food production. The contract type is recognized by authorities and grants use rights to agriculture entrepreneurs, which can be disrupted at any moment. The certificate of customary ownership reflects the registered state land for the land rights. This land document provides agricultural entrepreneurship with the legal title and registered record, but not full security for the land exploited. The land title indicates the absence of corruption and conflicts. Only 18% of the land exploited by agricultural entrepreneurs has a land title.

According to the *t*-test value, land access mode factors (occupation, heritage, and donation) have a significant effect on agricultural entrepreneurial activities. This confirms that land tenure security is a crucial factor for agricultural entrepreneurial activities and a key component for sustainable food production and biodiversity protection. Socioeconomic factors (financial assistance from parents or friends, land availability, agricultural experience, microfinance or bank loans, autonomy decision, and activity profitability) also have a significant impact on agricultural entrepreneurial activities.

On the basis of the findings of the study, some recommendations are proposed.

The government should assess the implications and impact of land law because of the legal dualism created by the coexistence of customary and modern rights, the vulnerability of legal land security, and land information management. In practice, the impreciseness of these two types of rights leads to land insecurity, which makes the land vulnerable and subject to all sorts of misappropriation.

Agriculture entrepreneurs should protect their investments by obtaining a land title document for their land.

Other partners, who intervene in food security systems, must facilitate the process of accessing the land security documents because land tenure security safeguards agricultural entrepreneurship and sustainable food production, which is the basis of food security, job creation, and reducing poverty.

All stakeholders in land tenure systems should address, in particular, women's access to agricultural land despite the dominant culture's discrimination, as the majority of women are still in the agriculture sector and at the center of food system production.

Author Contributions: Conceptualization, B.D.A. and S.A.A.; methodology, B.D.A.; validation, I.G.A., B.C.P.O. and M.N.B.; formal analysis, B.D.A.; writing—original draft preparation, B.D.A.; writing—review and editing, B.D.A., I.G.A. and S.A.A.; visualization, B.C.P.O.; supervision, M.N.B.; project administration, M.N.B.; funding acquisition, B.C.P.O. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding. The funding of the publication costs for this article has kindly been provided by the responsible land policy project of GIZ in Benin (Promotion d'une Politique Foncière Responsible: ProPFR/GIZ).

Acknowledgments: The case study is based on the activities of the responsible land policy project of GIZ in Benin, in collaboration with Laboratoire Société–Environnement (LaSEn) (University of Parakou) and Uganda Martyrs University. The responsible land policy project is implemented by Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH (www.giz.de).

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

Disclaimer: The content of the publication reflects the personal views of the authors and not those of GIZ.

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How Urban Expansion Triggers Spatio-Temporal Differentiation of Systemic Risk in Suburban Rural Areas: A Case Study of Tianjin, Chin

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Abstract: Rapid urban expansion has strongly impacted rural development in China's suburbs. The increasing probability of socio-ecosystem hazards, such as the shrinking and fragmentation of ecological space, the outflow of labor force, the disintegration of traditional society, and the decline in collective economy has become a systemic risk restricting the sustainable development of rural areas in the suburbs. At present, the influence of urban expansion on rural systemic risk in the suburbs is not clear, which is not conducive to putting forward differentiated and targeted strategies for rural revitalization. Therefore, in this study, we propose the ecological, industrial, social, and livelihood elements of rural systemic risk in the suburbs and construct a multi-dimensional risk resistance analysis framework involving functionality, stability, and sustainability. Taking 93 villages in the western suburbs of Tianjin as an example, and using spatial econometric methods such as remote sensing interpretation, GIS analysis, multiple linear regression, and random forest model testing, we analyze the relationship between external transportation construction, urban employment attraction, construction of land growth, rural risk factors, and the dimension of risk resistance. Finally, the influence of urban expansion on the spatial–temporal differentiation of rural systemic risk and the risk management strategy are discussed. The results show that the difference in the urban expansion intensities is the main factor of the spatial differentiation of rural systemic risk in the suburbs. With the acceleration of the land replacement rate between urban and rural areas, the proportion of urban construction of land is increasing, leading to various degrees of change in the rural land use pattern and the ecological security pattern. Meanwhile, because of the urban employment attraction, part of the rural labor force continues to decrease, leading to the spatial differentiation of rural industrial risks and social risks aggravated. Precise risk management strategies are put forward according to the systemic risks in different types of villages. In villages with a high proportion of urban construction land and inefficient land consolidation, ecological restoration projects should be carried out. For villages severely divided by transit roads, internal spatial connections should be strengthened by constructing public transport. For villages with good accessibility, the allocation of rural non-agricultural industries and service facilities should be strengthened to mitigate the impact of urban expansion on the rural social structure. From the perspective of risk management, the research results will provide a basis for making decisions regarding rural public policymaking and spatial resource allocation in the suburbs of developing countries.

Keywords: urban expansion; suburbs; systemic risk; risk resistance; differentiation; management policy

Citation: Tian, J.; Zeng, S.; Zeng, J.; Wang, S. How Urban Expansion Triggers Spatio-Temporal Differentiation of Systemic Risk in Suburban Rural Areas: A Case Study of Tianjin, China. *Land* **2022**, *11*, 1877. https://doi.org/10.3390/land11111877

Academic Editors: Carmen Delgado Viñas and María L. Gómez-Moreno

Received: 2 October 2022
Accepted: 19 October 2022
Published: 22 October 2022

1. Introduction

Risk refers to the possibility of an adverse outcome of an event, and systematic risk refers to the multiple risks resulting from the interaction of various interrelated risk factors [1]. The rural systemic risk discussed in this paper refers to the increasing probability of the occurrence of social ecosystem hazards, such as shrinking and fragmentation of ecological space, labor outflow, disintegration of traditional society, and collective economic recession, under the influence of urban expansion in suburban rural areas.

At present, developing countries are experiencing the stage of rapid urbanization, because of which, suburban villages show high complexity and rapid change and are easy to destroy [2,3]. Rural ecological security, industrial development, social stability, people's livelihood, and other aspects are strongly impacted, resulting in the coexistence of multiple systemic risks [4,5]. To resolve suburban rural systemic risks and realize urban–rural coordination and sustainable development, developing countries must accurately identify suburban rural systemic risks under the impact of urban expansion and interpret their formation mechanism.

The academic circle has carried out research on rural risk in the suburbs, with partial success. Improvements are still needed in three areas. In terms of research content, emphasis is placed on ecological risks and less attention is paid to social, industrial, and livelihood risks. In terms of spatial scale, there is a lack of mesoscale research on the administrative village as a unit. In terms of research methods, there are few studies on the spatial and temporal distribution of risks. Let us look at the three areas in detail.

In terms of research content, ecological, environmental, and health risks are paid the most attention, with warnings regarding environmental pollution, ecological damage, and ecological risk as the research focus. For example, soil and water pollutants sources and prevention measures were proposed through the analysis of the ecological risk index (RI) for soil and water pollution in rural areas caused by urban expansion [6]. ArcGIS spatial analysis technology was used to analyze the risk of rural water damage, and measures were put forward to protect natural vegetation and build rural sewage treatment facilities [7]. Analyzing the relationship between cultivated land use intensity and ecological risk and identifying the change in cultivated land use can help control ecological risk in advance [8]. The above methods help people to understand the changes in rural ecological patterns resulting from urban expansion and lay a foundation for solving the problems of the rural environment and health risks. However, due to the failure to consider the interaction between rural industrial development, social stability, people's livelihood demand, and ecological environment, there is a lack of studies on the impact of various complex factors of urban expansion on rural risk resistance and insufficient analysis of the correlation mechanism of the spatial–temporal differentiation of risk. Therefore, it is difficult to put forward an implementable rural risk management strategy systematically.

In terms of spatial scale, some scholars focus on analyzing large-scale rural temporal and spatial scope, while others analyze rural risks from the perspective of the micro-farmer unit and the livelihood vulnerability of rural communities and residents in the suburbs becomes the focus [9]. For example, on the basis of social interviews, it was suggested that diversified livelihoods should be developed to improve individuals' risk adaptation capacity as natural resources in rural areas decrease day by day [10]. The livelihood vulnerability index (LVI) and factor analysis were used to analyze the livelihood vulnerability of mixed urban and rural communities, and it was pointed out that the rural areas in the suburbs are less dependent on natural resources and the coordinated livelihood model with cities has not yet been formed [11]. The adaptation mechanism of rural social-ecosystemic risks in response to tourism development was put forward after carrying out a household survey of peasants [12]. The above analyses have provided practical help in formulating rural macro-strategies and laid a research foundation for solving the individual problems of farmers. However, there are few studies on the spatio-temporal differentiation of various risks taking villages as data units and there is a lack of mesoscale risk analysis combining the characteristics of different villages. Therefore, it is not easy to formulate public policies adapted to the characteristics of different villages, nor can it provide adequate technical support for the precise allocation of rural public resources.

In terms of research methods, there are standard statistical analysis and index evaluation methods for assessing rural vulnerability. For example, the nonlinear principal component method was used to assess the driving factors of rural socio-economic vulnerability in the suburbs, including employment opportunities, government effectiveness, and natural resources [13]. The abstract statistical classification method was used to analyze the relationship between rural economic diversity and economic risk minimization, and the development of specific types of rural economic activities was proposed [14]. A vulnerability evaluation model was built to analyze the temporal and spatial differentiation characteristics of rural production space vulnerability and summarize the types of rural industrial vulnerability [15]. The above research methods have achieved positive results. However, further research is needed to accurately understand the spatial and temporal distribution characteristics of rural risks and scientifically analyze the influence of urban expansion on various rural risks by combining statistical analysis and spatial measurement methods.

Therefore, in view of the problems in the existing research results, in this paper, we have added the research on social, industrial, and livelihood risks to the research content; strengthened the mesoscale village unit analysis on the spatial scale; and applied the spatial econometric analysis technology in the research method. This study takes villages as data units and uses spatial econometric analysis technology to analyze the spatio–temporal differentiation characteristics and formation mechanism of rural systemic risk in suburban areas under urban expansion. It will lay a theoretical foundation for accurately formulating public policies and allocating public resources to effectively resolve rural systemic risks in the suburbs and provide technical research support.

2. Study Context and Data Sources

2.1. Research Scope

Tianjin is one of the four municipalities directly under the central government in China and the second-largest city in northern China. From 1988 to 2018, the urbanization rate increased from 48.5% to 83.2%. The land use, social economy, and ecological space of the suburbs of Tianjin changed dramatically [16]. In this study, we selected 93 administrative villages in four towns (Yangliuqing Town, Xinkou Town, Duliu Town, and Yangfengang Town) in the western suburbs of Tianjin as the research area (Figure 1). The research area is located in the hinterland of the Beijing–Tianjin–Hebei city conglomeration, close to the Tianjin–Xiongan New Area spatial development corridor. Compared with other areas in the suburbs of Tianjin, in the western suburbs, urban space expansion is rapid and strongly influences rural development. It is a representative sample for studying the rural systemic risk in suburbs under the impact of rapid urban expansion.

The research scope included the inner suburbs, the middle and far suburbs, and other location types and covered all kinds of functional spaces on the urban fringe. For example, Yangliuqing Town is close to the urban area, so urban and rural space is intertwined and most villages are highly urbanized; the villages in Xinkou Town have developed modern agriculture practices and rural service industries; many villages in Duliu Town are located in the flood detention area and are ecologically sensitive; and the majority of villages in Yangfengang Town are based on traditional agricultural production and the development level is relatively backward. Meanwhile, the number of villages within the research scope (93) conformed to the research needs of rural risk in urban suburbs on the mesoscale. Diversified spatial types and a reasonable number of villages provided essential conditions for studying the spatial differentiation characteristics of rural systemic risk in the suburbs.

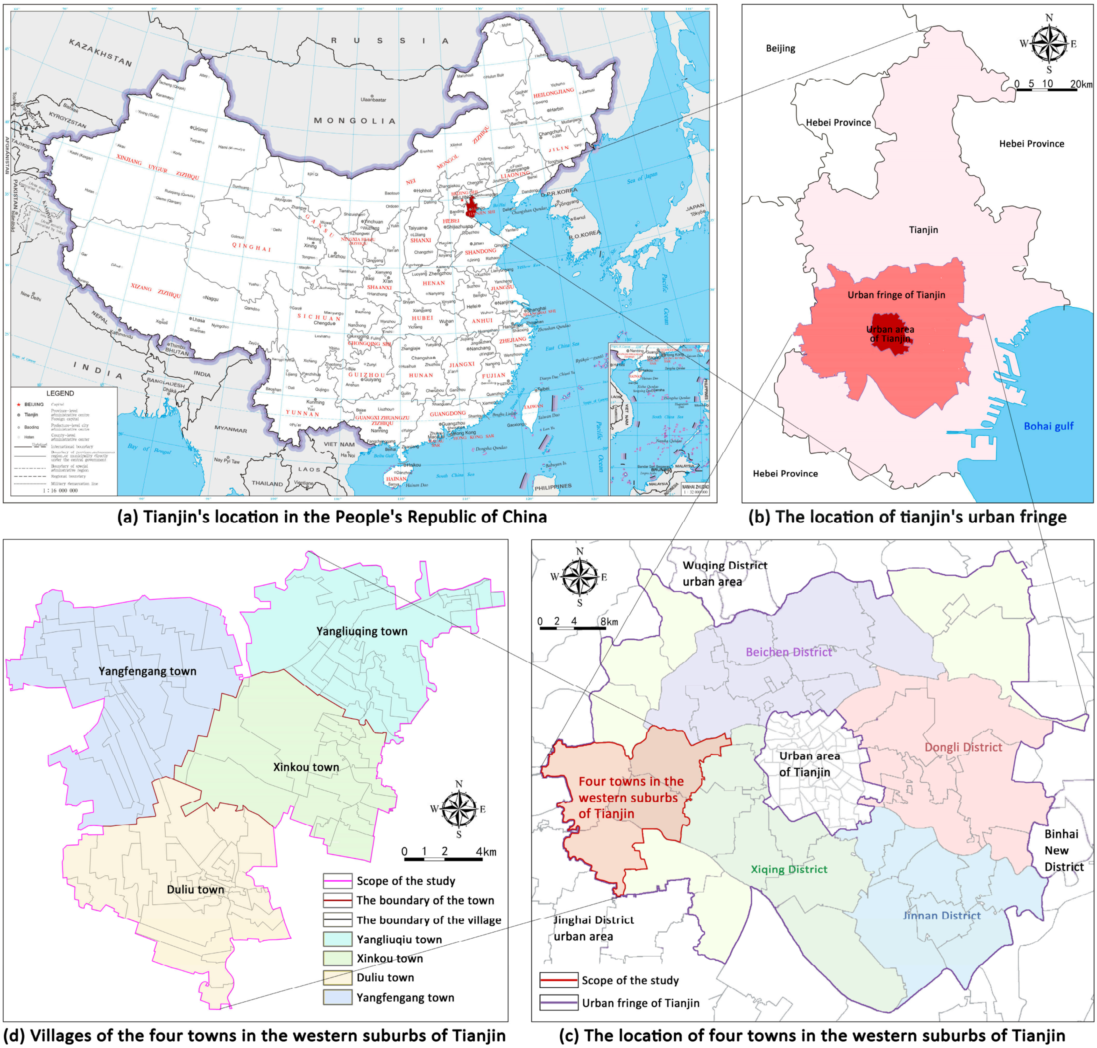


Figure 1. Location of the research area. (**a**) The location of Tianjin in China, (**b**) the extent of the suburbs of Tianjin, (**c**) the extent of the four towns in the western suburbs of Tianjin, and (**d**) the administrative boundaries of the 93 villages in the western suburbs of Tianjin (source: self-drawn).

2.2. Data Sources

2.2.1. Acquisition of Land Use and Road Traffic Data

Using Geospatial Data Cloud, we obtained Landsat 7 and Landsat 8 remote sensing image data (1998–2018, with a spatial resolution of 30 m and 15 m, respectively). We apply ENVI image data processing technology to interpret remote sensing image data as land use spatial vector data that can be processed by the GIS platform. The vector data of all roads in rural areas in the western suburbs of Tianjin were downloaded via the Universal Maps Downloader, which provides data support for calculating traffic accessibility and external road density (Table 1).

Table 1. Data information.

Data	Utility	Data Source
Land use data	Spatial stability, ecological resource richness, proportion, and change in construction land can be calculated, and rural ecological risks can be analyzed.	Landsat 7 and Landsat 8 remote sensing images, which can be downloaded through a geospatial data cloud platform and interpreted through ENVI
Boundary data of administrative villages	It can support the study of spatial differentiation with the village as a unit.	Database of Bazhou City Planning Bureau and Tianjin Urban Planning and Design Institute
Road data	It can be used to calculate traffic accessibility, external traffic road density, etc., and analyze the degree of influence of urban expansion.	Omnipotent electronic map download software
Socio-economic data	It includes data on population, industry, employment, land transfer, income, collective economy, public service facilities, etc., which can be used to analyze the risks to the rural industry, society, and people's livelihood.	Questionnaire surveys, interview records, and Internet data search (http://www.tcmap.com.cn/tianjin/xiqingqu.html, accessed on 9 November 2019)

Source: self-created.

2.2.2. Acquisition of Socio-Economic Data

This research mainly involved a literature review of books, papers, and Internet materials and adopted social research methods, such as questionnaire surveys and interview records. Questionnaires were sent to the village managers in each administrative village to acquire data related to rural social, industrial, and livelihood factors and analyze the development situation of the village (a questionnaire was sent to each village within the scope of the study, for a total of 93 questionnaires, and 93 valid questionnaires were recovered). Meanwhile, village cadres and some villagers in each village were interviewed to understand the village's collective or private economic development. Then, the reliability of data, such as the labor outflow level, residents' income, the land transfer ratio, and rural service facilities, was verified.

3. Methodology

3.1. Research Framework

The impact of urban expansion on different villages in the suburbs is spatially and temporally different. Therefore, the systematic risk resistance capacity and various risk factors of rural areas also show different characteristics across villages. The impact of urban expansion on suburban villages is mainly reflected in the impact of transit traffic construction, the attraction of urban employment to the rural labor force, and the embedding of urban construction land into rural areas [17]. Therefore, based on GIS technology, in this study, we first calculate the density of transit roads in each village, the commuting time from each village to the urban area, and the proportion of urban construction land areas embedded in the countryside and identify the spatial characteristics of urban expansion to the suburban countryside. Meanwhile, on the basis of multi-source data statistics and GIS technology, we analyze the spatial differentiation characteristics of industrial, social, livelihood, and ecological factors of rural systemic risk and the spatial differentiation characteristics of functional, stability, and sustainability factors of rural resistance to risk. Then, we analyze the correlation mechanism between urban expansion and spatial differentiation of rural systemic risk. We use Pearson correlation analysis to extract influential correlation factors and use multiple linear regression analysis and a random forest model test to determine the core correlation factors. Finally, we use the logic analysis method to analyze the mechanism of action between core correlation factors and clarify the spatial differentiation law of risk factors and the ability to resist suburban rural systemic risk under the influence of urban expansion (Figure 2).

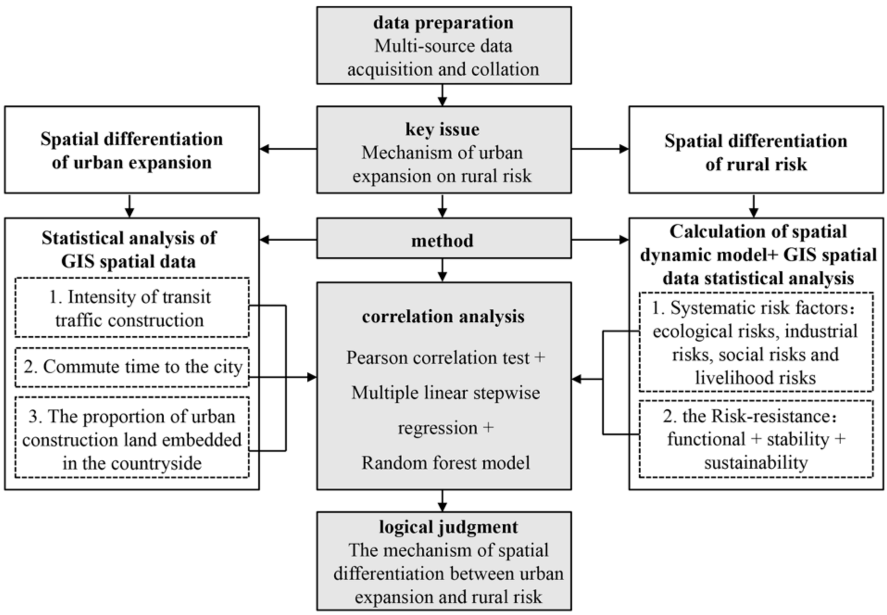


Figure 2. Research framework of spatio-temporal differentiation and mechanism of rural systemic risk under the influence of urban expansion (source: self-drawn).

3.2. Observed Variable

3.2.1. Observational Variables of the Impact of Urban Expansion on Suburban Rural Risk

The factors of urban expansion that influence rural systemic risk are mainly reflected in the following aspects: ① The construction of transit traffic outside the city will interfere with the ecological pattern and industrial development of the suburbs, so the density of external roads in each village can be selected as the corresponding observation variable of transit traffic construction [18]. The higher the road density, the greater the interference intensity of transit traffic to the village. ② The changes in service radiation and employment attraction intensity in urban areas will have an impact on rural population composition, industrial development, and social stability, which can be represented by the commuting time from the village to the central city [19]. The shorter the commute time, the better the accessibility, indicating that the village is more influenced by the attraction of urban employment and public services. ③ The embedding of urban construction land into rural areas refers to replacing rural land with urban land for industry, universities, and large markets. It tends to reduce the space of rural ecology, living, and agricultural production, which can be represented by the proportion of urban construction land embedded in suburban villages [20]. ④ Urban expansion may cause pollution in the rural environment, and the pollution degree can be represented by the air quality index (AQI) of the atmospheric environment and the related index of water pollution [21]. In this paper, we mainly discuss the first three aspects.

3.2.2. Observational Variables of Rural Systemic Risk Factors in Suburbs

Rural systemic risk influences industry, society, people's livelihood, ecology, and other contents (latent variables). According to the representativeness and accessibility of the related data, we select the observed variables of the following risk factors (Table 2). The variable "proportion of agricultural employees" can be selected in terms of industrial elements. If the value of this variable is too high, it reflects that the industry type is too single; a too-low value it indicates that the foundation of endogenous-characteristic industries in rural areas is insufficient and these industries are vulnerable to the impact of urban industries [22]. The variable "proportion of labor outflow" can be selected in terms of social factors. A high proportion of labor outflow indicates that the human base of social development is weak and the social structure is unstable [23]. The variable "employment diversity index" can be selected in terms of livelihood factors. A low value of this variable indicates that the employment type is single and employment is unstable [24]. The "average area of ecological patch" index can be selected in terms of ecological factors. A low value of this index indicates that ecological patch fragmentation is severe and ecological risk is high [25].

Table 2. Observational variables of systemic risk factors in suburban villages.

Latent Variable	Observational Variable	Risk Characterization
The sustainable development level of the rural industry	The proportion of agricultural employees [22]	Too high or too low
	The proportion of land transfer [2,17]	Not suitable for farming needs
	Arable land per capita [8]	Too little
	Main types of non-agricultural industries [12,17]	Low end
	Main types of farming [17]	Low economic benefit
	The development level of collective and private economy [17]	Low
	The per capita area of industrial land [15]	Too large
The stable level of the rural social structure	The spillover ratio of labor outflow [23]	High
	The magnitude of population change [17,24]	Rapid
	The density of the population [13,26]	Low
	Housing vacancy rate [12]	High
	The frequency of group activities organized [17]	Low
	The percentage of support group coverage [17]	Low
The level of prosperity and facilities in the countryside	Employment diversity index [24]	A single type of employment
	The number of primary and secondary schools within 1 km [17,22]	Insufficient
	The number of health facilities within 1 km [17]	Insufficient
	The number of bus stops within 1 km [17,22]	Insufficient
	Commuting time to and from the city [15,24]	Long
	Average annual household income [11,12]	Low
Rural ecological pattern stability and resource richness	The average area of the ecological patch [25]	Plaque too fragile
	The percentage of ecological vegetation coverage [3,27]	Low
	The percentage of water area coverage [3,17]	Low
	The percentage of farmland coverage [8]	Low
	The rate of overall spatial change [27]	Rapid
	Ecological space resource index [17,28]	Less ecological resources

Source: self-created.

3.2.3. Observational Variables of Rural Risk Resilience in Suburban Areas

The functionality, stability, and sustainability of the system development can characterize rural risk resistance. The more functional the rural development, the more developed the economy, the richer the villagers, and the stronger the ability to resist economic risks. The more stable the rural development, the more diverse the employment of residents, the more stable the population and spatial changes, and the stronger the inheritance of local culture, indicating that the rural ability to resist social risks is strong. The higher the sustainability of rural development, the more perfect the natural ecosystem service function, and the stronger the ability of the rural area to resist environmental risks. Therefore, we selected these three aspects as potential variable indicators to measure rural risk resistance ability and the corresponding observation variable indicators for each type of potential variable according to the typicality and accessibility of variables [29–31] (Table 3).

Table 3. Observational variables characterizing rural risk resistance.

The Dimension of Ability to Resist Risk	The Subdivision Dimension of Risk Resistance	Resilience Targets against Risk	Primary Observed Variable
System functionality	The abundance of the villagers' lives	Good economic performance of peasant households	Annual household income [11,12]
	The level of collective economy	Prosperous collective industries	The annual income of village collective [17,29]
	Job diversity	Strong livelihood security	Employment diversity index [24]
System stability	The effectiveness of ensuring people's well-being	Guaranteed public services	The number of facilities per kilometer radius [17,30]
	The reasonableness of population composition	Stable social structure	The level of labor outflow [23]
	The stability of land use	Stable spatial structure	The rate of spatial change [27,31]
System sustainability	The effectiveness of ecosystem services	Good function of the ecosystem	Ecological space resource index [17,28]
	The integrity of the ecological security pattern	Secure ecological patterns	The average area of the ecological patch [25]

Source: self-created.

3.3. Methods of Spatial Econometric Analysis

The research on the correlation between urban expansion and spatial differentiation of suburban rural systemic risk involves analyzing the correlation between the projected values of certain urban expansion elements in each rural space unit and the numerical matrices of risk elements in each space unit (Figure 3). It mainly involves spatial econometric analysis methods, such as spatial information statistics, spatial change rate model calculation, and spatial data analysis.

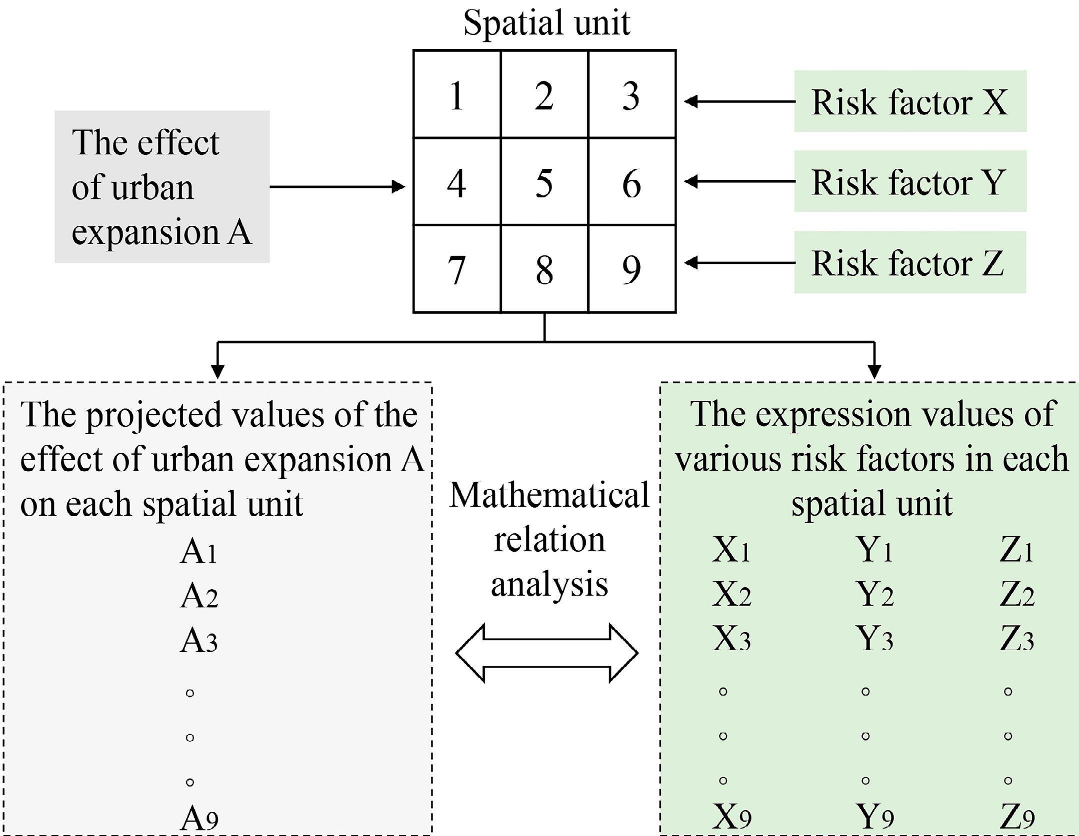


Figure 3. The principle of mathematical correlation analysis between urban expansion and the rural systemic risk (source: self-drawn).

3.3.1. Method of Calculating Spatial Information Statistics and the Spatial Change Rate Model

The spatial and temporal distribution characteristics of the rural systemic risk can be identified by processing land use data interpreted by remote sensing and calculating social and economic data through the GIS platform. The spatial change rate model is used to quantitatively analyze the rates of change of various types of land use in suburban rural areas and analyze the ecological risk pattern from the perspective of stability. It includes the rates of change of single land use and comprehensive land use. The rate of change of single land is expressed in Formula (1).

$$K = \frac{U_a + U_b}{U_1} \times \frac{1}{t_2 - t_1} \times 100\% \quad (1)$$

Here, K is the rate of change of single land use, $t_2 - t_1$ is the duration of the study period, U_1 is the initial annual area of a certain type of land within the research scope, U_a is the increased area (absolute value) of this type of land during this study period, U_b is the area (absolute value) reduced by this type of land in this study period, and $U_a + U_b$ is the total dynamic change in the area of this kind of land use in this research period.

The comprehensive land use change rate refers to the overall rate of change in the scales of all types of land use in the study area in a certain period, expressed in Formula (2).

The change rate of extensive land use reflects the overall stability of land use: the higher the dynamic attitude, the more unstable the space and the higher the ecological risk.

$$LC = \frac{\sum_{i=1}^{n} \Delta LA_{(ij)}}{\sum_{i=1}^{n} LA_{(ij)}} \times \frac{1}{t_2 - t_1} \times 100\% \quad (2)$$

Here, LC represents the rate of change of comprehensive land use, $\Delta LA_{(ij)}$ represents the absolute value of the land area (category i land and non-category i land) during the study period, $LA_{(i,t_1)}$ is the area of the category i land in the study area at the initial monitoring time t_1, and $t_2 - t_1$ represents the duration of the research period [27].

3.3.2. Correlation Analysis Method of Risk Factors Based on the Multiple Regression Model

Multiple linear stepwise regression methods can be used to screen out the optimal set of variables under the condition of mutual influence of multiple variables in the system [32]. Therefore, this method is suitable for screening rural risk factors strongly associated with a specific urban expansion function in this study as a basis for further logical analysis. The expression of the multiple linear regression model is as follows (Formula (3)):

$$A = \beta_0 + \beta_1 D_1 + \beta_2 D_2 + \beta_3 D_3 + \cdots + \beta_P D_P + \varepsilon \quad (3)$$

where A is the target variable (the observed variable of a specific urban expansion effect in this study); β_0 is the regression constant; β_1, $\beta_2 \ldots \beta_P$ is the regression coefficient (which can represent the strength of the correlation in this study); D_1, $D_2 \ldots D_P$ is the influential observational variable of various risk factors in the affected villages; and ε is a random error [33].

3.3.3. Method of Risk Factor Correlation Analysis Based on the Random Forest Model

Random forest is a kind of advanced algorithm based on a decision tree. Its important function is to identify the importance of complex system elements [34]. This fits the analysis demand of correlation intensity between urban expansion and various elements of rural systemic risk in this study. In this study, the out-of-pocket data method of random forest is used to rank the correlation intensity between a particular urban expansion effect and various risk factors in the suburbs and countryside to screen out the core elements associated with the urban expansion effect logical analysis.

4. Results

4.1. Spatial and Temporal Differentiation of Urban Expansion to the Suburban Countryside

Our study shows that during the period of rapid urbanization (1988–2018), the expansion effect of Tianjin city to the western suburbs was prominent and the growth of urban construction land, the density of transit roads, transportation accessibility, and other spatial factors changed significantly. The hot spots of spatial change shifted from the inner suburbs to the outer suburbs and were mainly concentrated in the villages around the towns or along the traffic corridors.

4.1.1. Changes in the Density of Suburban Transit Roads

From 1988 to 2018, the external transport construction in the western suburbs of Tianjin showed apparent spatial heterogeneity among different villages. In terms of railways, an east–west line was added (Tianjin–Baoding High-speed Railway). Three new expressways emerged, among which the Beijing–Shanghai expressway runs through the study area from north to south. Meanwhile, the road density in the connecting direction between each town and the central urban area improved significantly. The road construction sequence ran from the inner suburbs (eastern) to the outer suburbs (western). The density of transit roads generally presented the spatial distribution characteristics of "dense inner suburbs, sparse outer suburbs" and "high intensity around towns" (Figure 4).

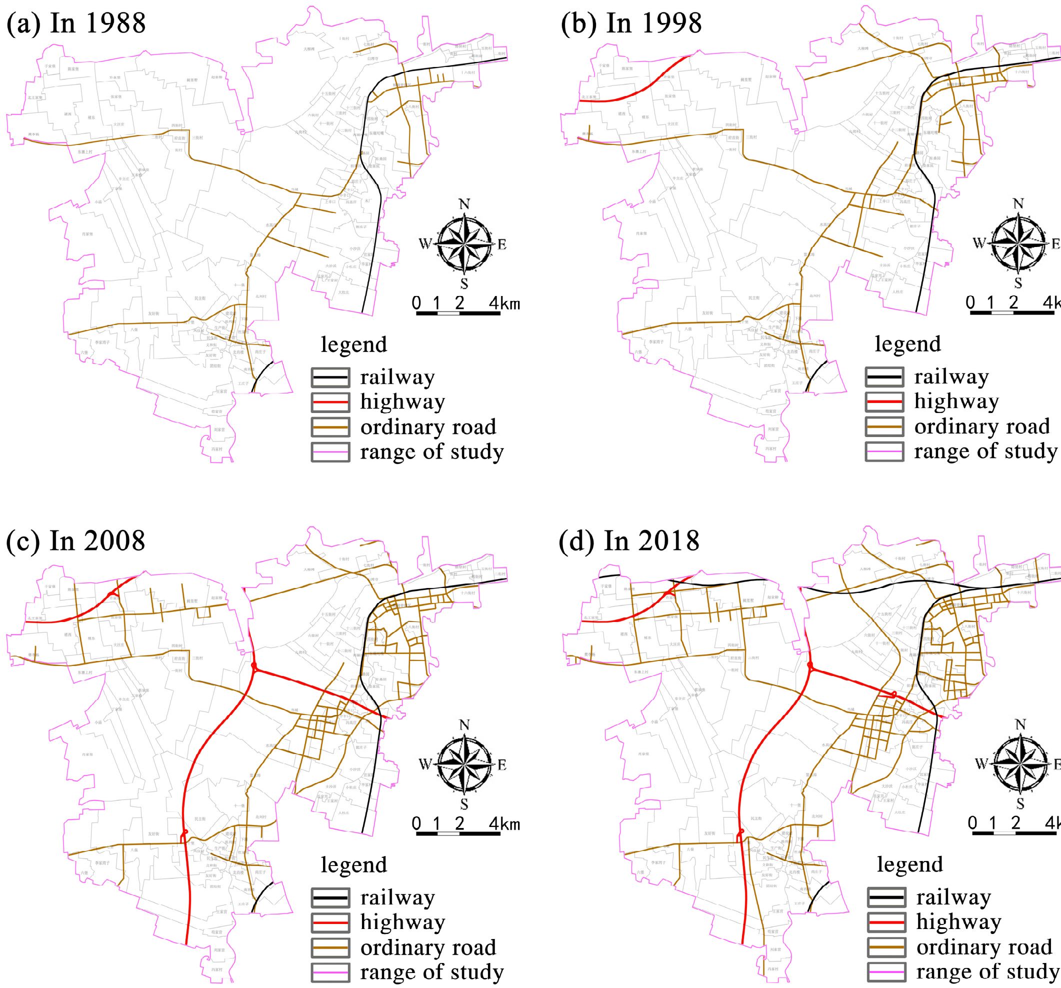


Figure 4. Changes in the rural external traffic network in the western suburbs of Tianjin during various periods of urban expansion (source: self-drawn).

4.1.2. Changes in Rural–Urban Accessibility

The accessibility from rural areas to urban areas can reflect the attractiveness of urban employment services to rural areas. From 1988 to 2018, the transport accessibility of the western suburbs of Tianjin continued to change and showed significant spatial differences. The range of high accessibility (less than 30 min commuting time to the urban area) continued to expand from several villages in the northeast near the urban center to most of the areas covered by the study. The rural accessibility to urban areas in the southwest, which are far from the traffic corridor, was relatively low. Figure 5 shows the changes in accessibility. The color changes from darker to lighter represent the spatial difference in accessibility from weak to strong.

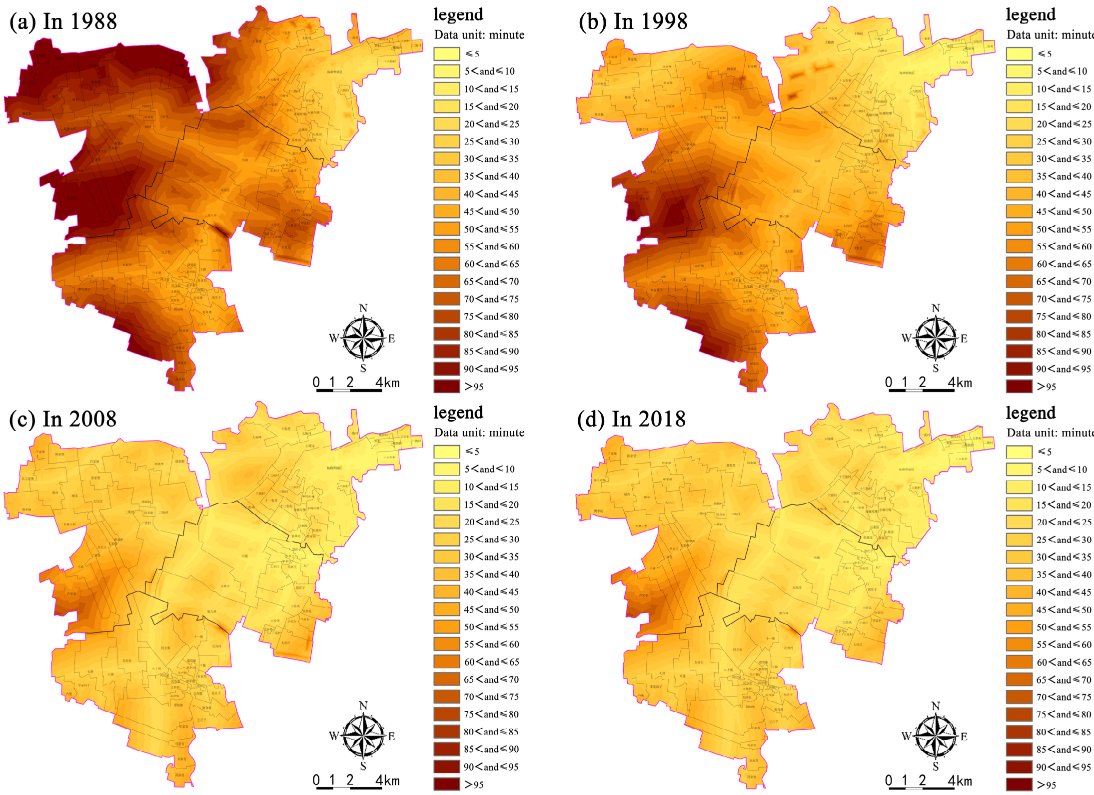


Figure 5. Change in rural accessibility to urban areas in the western suburbs of Tianjin during various periods of urban expansion (source: self-drawn).

4.1.3. Temporal and Spatial Changes in Urban Land Embedding in the Suburban Countryside

From 1988 to 2018, the embedding of urban construction land into rural areas in the western suburbs of Tianjin kept expanding and presented firm spatial heterogeneity. In 1988, the urban construction land in the western suburbs of Tianjin was concentrated in Yangliuqing Town, which was close to the urban area. Subsequently, urban construction land continued to expand from inner suburbs to outer suburbs. By 2018, urban construction land dominated the construction land of villages in Yangliuqing Town and a large amount of urban construction land also appeared in villages in other towns. The hotspots of urban construction land change were relatively concentrated, developing from point and line to strip and block and mainly distributed in the inner suburbs of the city (east of Yangliuqing Town) and industrial parks of each town (north of Yangfengang Town and south of Xinkou Town) (Figure 6).

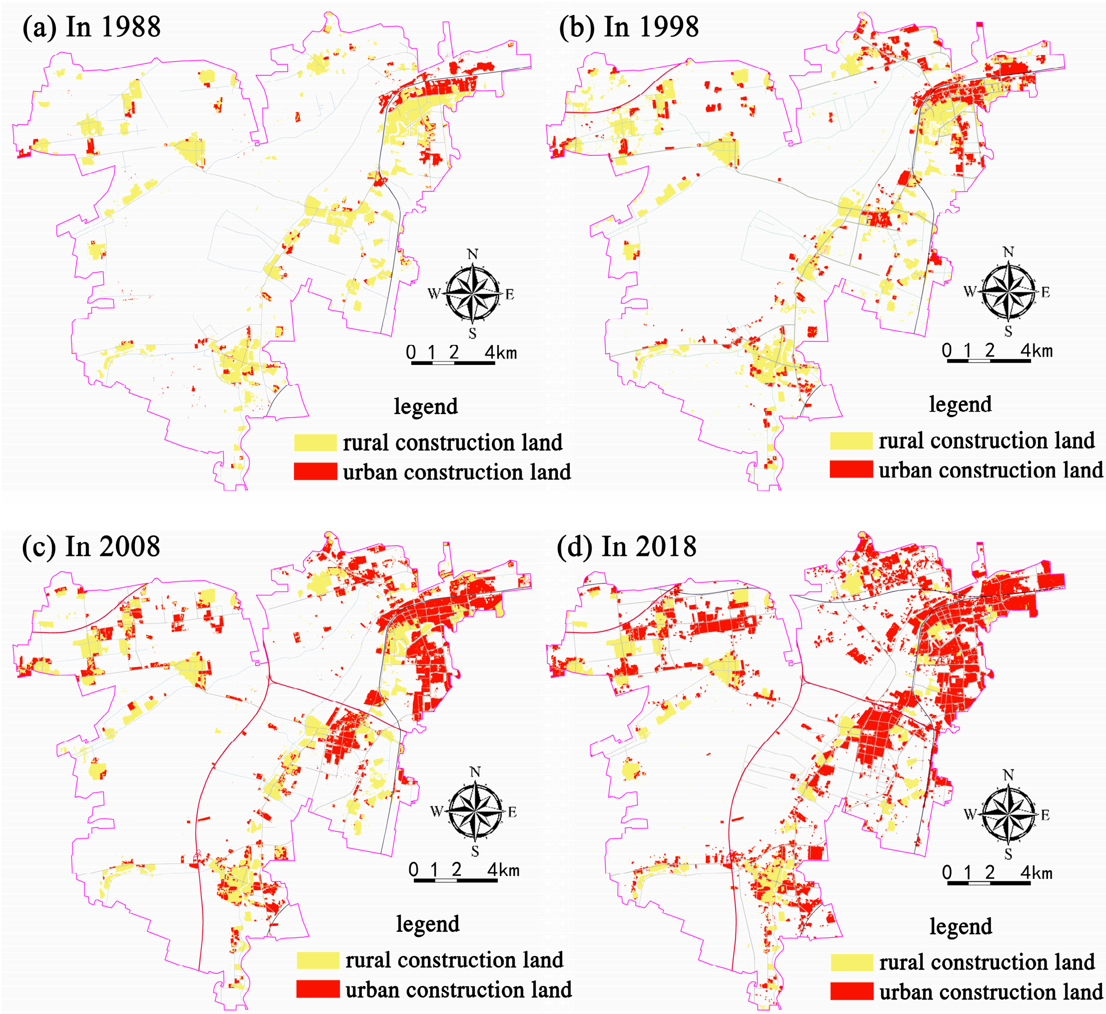


Figure 6. Changes in urban and rural construction land in the western suburbs of Tianjin during various periods of urban expansion (source: self-drawn).

4.2. Spatial Differentiation of Rural Systemic Risk under the Impact of Urban Expansion

The results show that under the influence of urban expansion, various systemic risk factors in rural areas show different degrees of spatial differentiation and the risk resistance capacity of different villages is significantly different.

4.2.1. Spatial Differentiation Characteristics of Systematic Risk Factors in the Suburban Countryside

Industry, society, people's livelihood, and the ecology of rural systemic risk in the western suburbs of Tianjin showed different degrees of spatial differentiation. Regarding industrial risk factors, land transfer in some middle and outer suburbs lagged behind the demand for agricultural development, which is not conducive to the large-scale and efficient development of agriculture. The collective economic development of some villages in the southwest was low, which is not conducive to the sustainable development of rural industries. In terms of social risks, the proportion of migrant workers around some towns and villages in the northwest was high, resulting in a significant outflow of the labor force, which is not conducive to the stable development of population and society. The collective governance capacity of the villages around some towns and villages in the inner suburbs was poor, and the cohesion and collective action capacity of the villages were insufficient. Regarding livelihood risks, some villages in central and western areas lacked facilities such as education and medical care, making it challenging to provide the villagers security in terms of health and education. At the level of ecological risk, the ecological patches in the villages in the inner suburbs, along the traffic corridors, and around towns were seriously fragmented and the ecological space resources supporting the sustainable development of rural areas had been destroyed. On the basis of the above risk factors, the villages with a high level of systemic risk were concentrated in two types of areas. One was the surrounding villages of Yangliuqing Town, which is close to the central urban area. The second was the outlying villages, represented by the western part of Yangfengang Port (Figure 7).

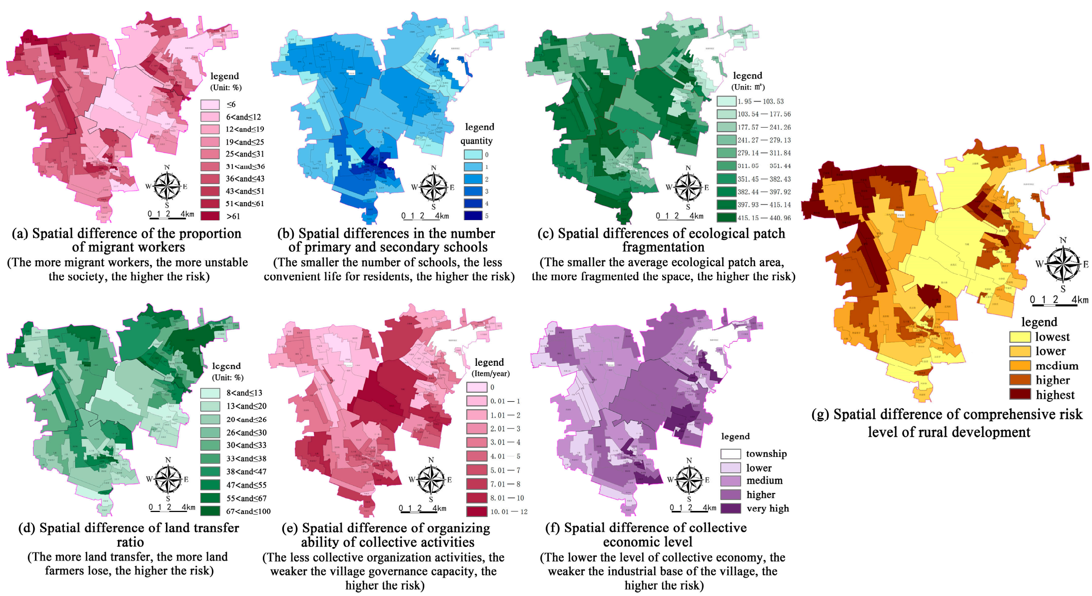


Figure 7. Spatial differentiation of rural systemic risk factors in the western suburbs of Tianjin (source: self-drawn).

4.2.2. Spatial Differentiation of Rural Risk Resistance in the Suburban Countryside

The rural areas in the western suburbs of Tianjin showed distinct spatial differences in different dimensions of risk resistance. Regarding function, the per capita income of some villages in the northwest was low, the residents were not wealthy, and the economic development performance was not high. In terms of stability, the rate of spatial change of villages in the inner suburbs and around towns was faster and the pattern of rural ecological security and industrial development was unstable. Some villages in the east and southwest had low employment diversity, and the single employment structure made it challenging to withstand sudden market risks. In terms of sustainability, the proportion of ecological land in the inner suburbs, industrial areas, and villages around towns was low. The resources of ecosystem services on which rural sustainable development depends were less, which is not conducive to the sustainable development of rural endogenous power. Overall, the villages with low risk resistance were concentrated in two areas. One is the surrounding villages of Yangliuqing Town, which is close to the central city. The second is the outlying villages, represented by the western part of Yangfengang (Figure 8).

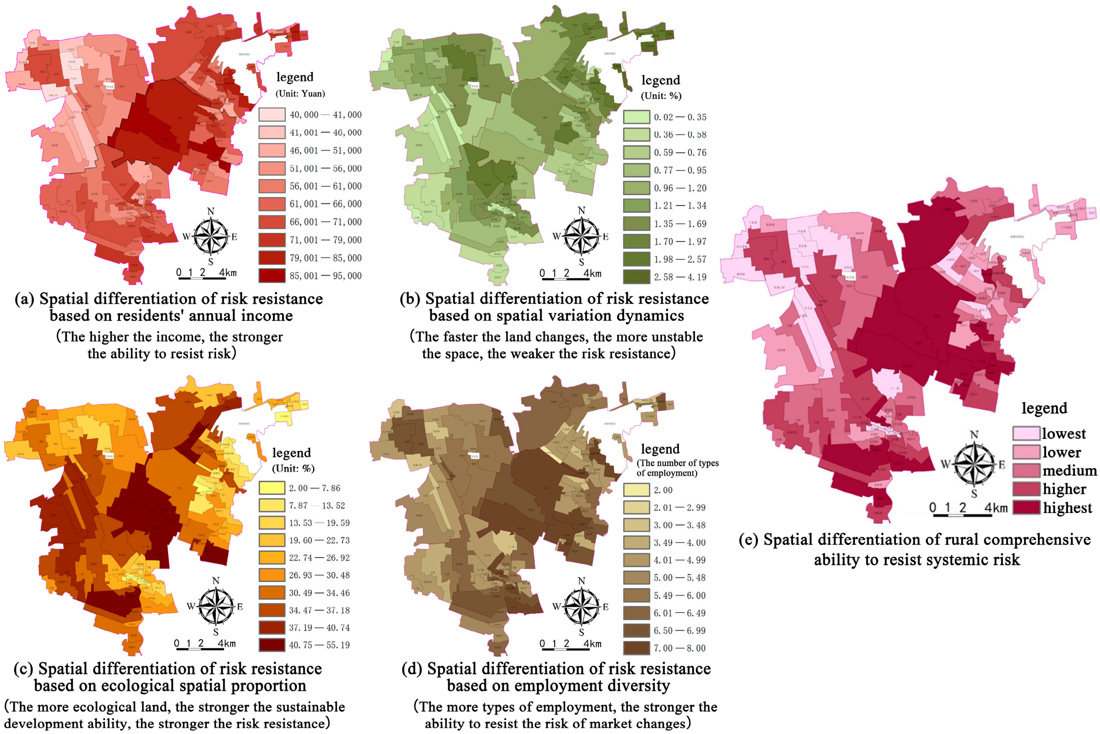


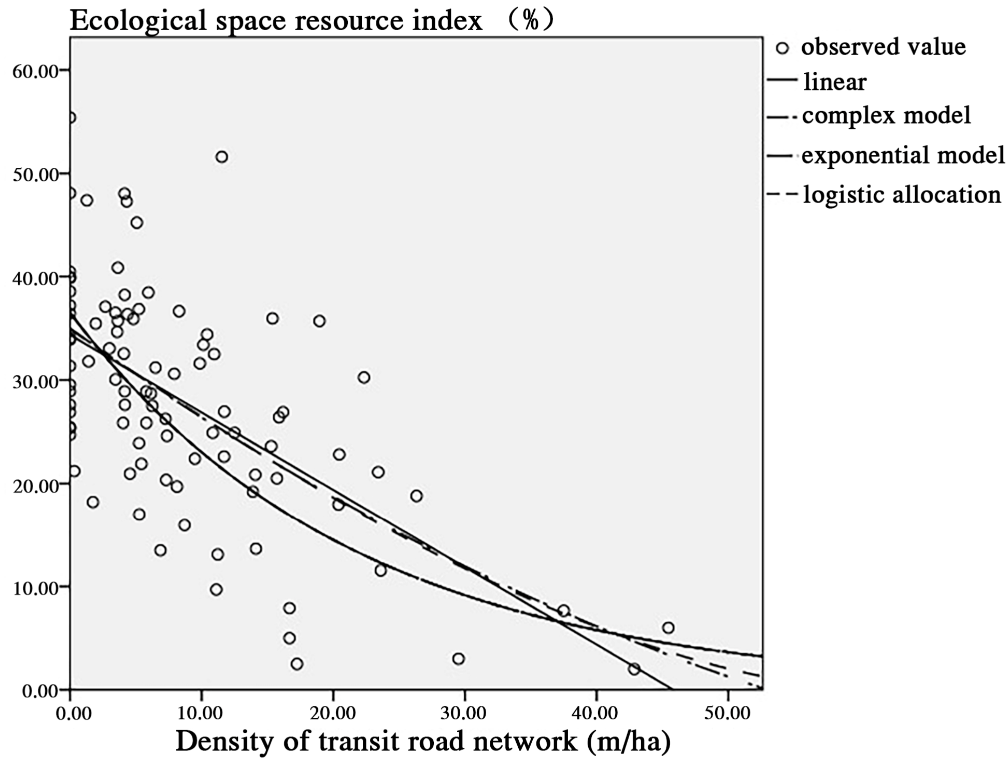
Figure 8. Spatial differentiation of rural resilience to risk in the western suburbs of Tianjin (source: self-drawn).

4.3. Correlation and Mechanism between Urban Expansion and Rural Risk Resistance

By analyzing the correlation between the urban expansion effect (transit road construction, urban employment service attraction, urban construction land embedding into rural areas), and various dimensions of rural risk resistance, we comprehensively analyzed the mechanism of urban expansion effect on suburban rural risk resistance.

4.3.1. Correlation between the Density of Transit Roads and Rural Risk Resistance

Studies show that transit road construction (the observed variable is road density) is significantly correlated with the ecological sustainability dimension of rural risk resistance (the observed variable is ecological space resource index) (Figure 9; Pearson correlation coefficient is over 0.6, and the reasonable degree of composite linear equation is within the acceptable range). The denser the transit road, the more serious the disturbance to the ecosystem, and the worse the rural ecological ability to resist risks. This shows that transit traffic disturbance is one of the main factors influencing rural ecological risk resistance and has a weak correlation with the economic function and social stability of the rural area.



(**a**)

correlation

		Density of transit road network (m/ha)	Ecological space resource index (%)
Density of transit road network (m/ha)	Pearson correlation	1	−0.619**
	Significance (two tails)		0.000
	N	93	93
Ecological space resource index (%)	Pearson correlation	−0.619**	1
	Significance (two tails)	0.000	
	N	93	93

. **The correlation was significant at 0.01 level (two-tailed)

(**b**)

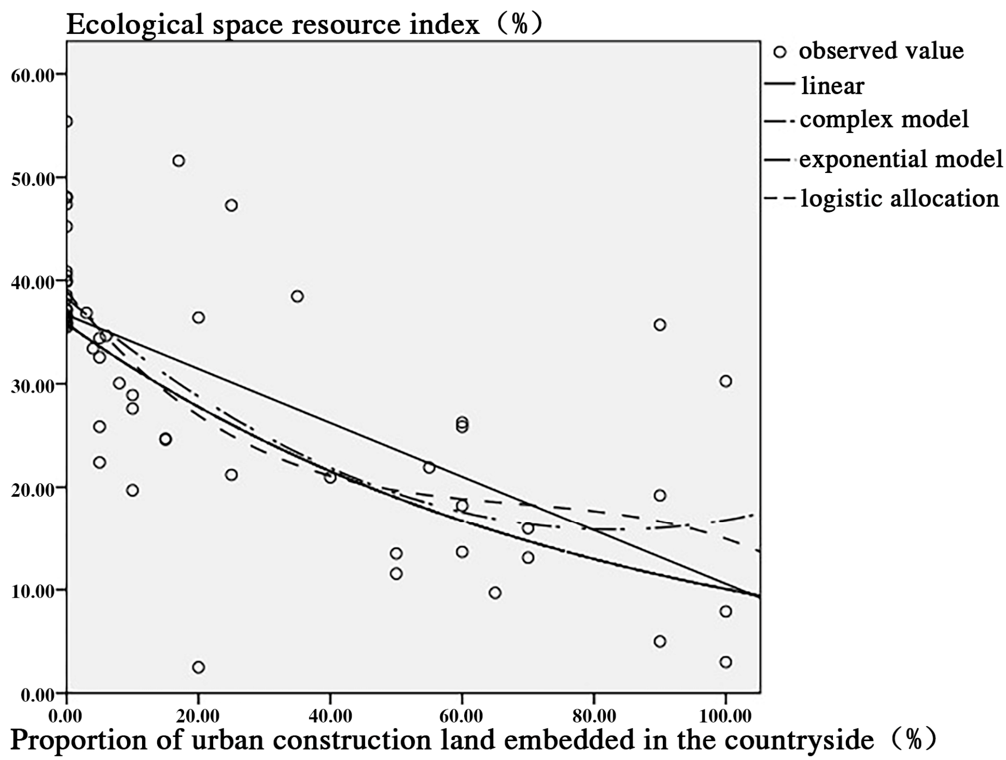
Figure 9. (**a**) Equation fitting analysis of the transit road density and the ecological space resource index (source: self-drawn). (**b**) Correlation analysis between the transit road density and the ecological space resource index (source: self-drawn).

4.3.2. The Correlation between Urban Employment Attraction and Rural Risk Resistance

The study shows a positive correlation between the difference in accessibility to urban areas and the level of income of villagers, which indicates that the convenience of obtaining urban employment has a particular impact on the risk resistance of the suburban rural economy. Meanwhile, the accessibility difference has a significant negative correlation with the sustainability of the rural ecological environment and social stability. The higher the accessibility, the faster the spatial change, the lower the proportion of ecological space, and the lower the ecological stability. The more convenient the urban employment choice, the more the rural labor outflow, indicating that the attractiveness of urban employment services is one of the main factors affecting the stability of the rural social structure.

4.3.3. Correlation between Urban Construction Land Embeddedness and Rural Risk Resistance

Studies show that the proportion of urban construction land in rural areas has a significant negative correlation with the sustainability of the rural ecology (Figure 10), while the correlation with the risk resistance of the functional dimension of the rural economy is weak. The higher the proportion of urban construction land embedded in rural areas, the faster the spatial change, and the lower the proportion of ecological space, the lower the ecological stability and sustainability. This indicates that the embedding of urban construction land is one of the main factors affecting the suburban rural risk resistance resulting from ecological sustainability.



(**a**)

Figure 10. *Cont.*

correlation

		Proportion of urban land embedded in countryside (%)	Ecological space resource index (%)
Proportion of urban land embedded in countryside (%)	Pearson correlation	1	−0.672**
	Significance (two tails)		0.000
	N	56	56
Ecological space resource index (%)	Pearson correlation	−0.672**	1
	Significance (two tails)	0.000	
	N	56	93

**. The correlation was significant at 0.01 level (two-tailed)

(**b**)

Figure 10. (**a**) Equation fitting analysis of the proportion of urban construction land and the ecological space resource index (source: self-drawn). (**b**) Correlation analysis between the proportion of urban construction land and the ecological space resource index (source: self-drawn).

4.4. Screening and Mechanism of the Core Factors of Urban Expansion and Rural Systemic Risk

4.4.1. Screening and Mechanism of Correlation Factors between Transit Road Density and Rural Systemic Risk

Firstly, SPSS Pearson correlation analysis was used to test the data correlation and the factors influencing the density of transit roads that were screened from various elements of rural systemic risk. Then, on the basis of multiple regression and the random forest model, the core correlation factors between road density and rural risk factors and their mechanism were further analyzed.

(1) Screening and mechanism analysis of influential correlation factors

The results show that the density of transit roads is negatively correlated with the average area of the ecological patch, the proportion of farmland, and the proportion of ecological vegetation, which shows that the density of transit roads aggravates the ecological risk by dividing the ecological space. Meanwhile, transit road density is positively correlated with population density and various public service facilities, indicating that this factor promotes the agglomeration of population and public service facilities by influencing transportation accessibility and changing the distribution pattern of social and livelihood risks. There is a significant negative correlation between the density of transit roads and the proportion of agricultural employees, which shows that areas with a high road density have a relatively high level of non-agricultural industry development and a relatively low proportion of agricultural employees, which reduces the risks to industry and livelihood from the perspective of diversified industry development (Table 4).

As per the above analysis, the transit road density is significantly correlated with variables of rural risk factors such as ecological patch fragmentation, land use, a permanent population, agricultural employment, village accessibility, and public service facilities. Therefore, the above variable types were extracted as influential correlation factors of the rural systemic risk under the influence of transit traffic construction. The mechanism is as follows: the higher the density and intensity of transit roads, the higher the proportion of construction land, and the lower the proportion of farmland and ecological vegetation reflects the interaction between transit roads and construction land expansion. Roads often pass through residential and industrial areas with more travel demands, and road construction improves spatial accessibility and promotes more population and construction activities. Moreover, the proportion of ecological space decreases compared with that of other villages, increasing ecological risks.

Table 4. Statistical analysis of the correlation between transit traffic network density and rural risk factors.

Variables of Rural Risk Factors	Pearson Correlation	Significance (Two Tails)
The proportion of agricultural employees	−0.363	0.000
The proportion of land transfer	0.202	0.052
Arable land per capita	−0.139	0.184
Main types of non-agricultural industries	——	——
Main types of farming	——	——
The development level of collective and private economy	——	——
The per capita area of industrial land	0.001	0.995
The spillover ratio of labor outflow	0.032	0.760
The magnitude of population change	0.202	0.053
The density of the population	0.689	0.000
Housing vacancy rate	−0.146	0.162
Employment diversity index	−0.062	0.553
The number of primary and secondary schools within 1 km	0.359	0.000
The number of health facilities within 1 km	0.219	0.035
Commuting time to and from the city	−0.432	0.000
Average annual household income	0.071	0.497
The average area of the ecological patch	−0.649	0.000
The percentage of ecological vegetation coverage	−0.249	0.016
The percentage of water area coverage	−0.189	0.069
The percentage of farmland coverage	−0.635	0.000
The rate of overall spatial change	0.137	0.189
Ecological space resource index	−0.619	0.000

Source: self-created

(2) Screening and mechanism analysis of core correlation factors

On the basis of the effective correlation factor types of rural systemic risk under the influence of transit traffic construction, the stepwise regression method of multiple linear regression analysis was adopted to screen out the core factors (the factors removed in the stepwise regression process can be regarded as non-core factors that have significant correlation and are indirectly affected by core factors).

According to the model abstract in the analysis results (the table on the left in Figure 11), the R-value of the regression equation is 0.792 and the adjusted R2 value is 0.611, indicating that the effectiveness of the interpretation adaptability of the regression results reaches 61.1%, which is within a reasonable range. According to the variance analysis (the table on the right in Figure 11), the F-value test value is 37.071 (Sig. = 0.000), indicating a high significance, proving that the regression equation has good effectiveness. After extracting regression constants and regression coefficients (Table 5), the multiple regression equation is as follows: $A = 6.412 + 0.399\ S_2 + 0.280\ S_8 + 0.165\ L_2 - 0.237\ L_5$.

Abstract of model

model	R	R square	Adjusted for R squared	Standard skew error
1	0.689 [a]	0.474	0.469	6.72862
2	0.760 [b]	0.578	0.568	6.06573
3	0.778 [c]	0.606	0.593	5.89037
4	0.792 [d]	0.628	0.611	5.75948

a. forecast: (constant), the population density (person/ha)
b. forecast: (constant), the population density (person/ha), proportion of construction land (%).
c. forecast: (constant), the population density (person/ha), proportion of construction land (%) and commute time to downtown (min)
d. forecast:(constant), the population density (person/ha), proportion of construction land (%), commute time to downtown (min), the number of schools within a kilometer

Anova analysis [a]

model		Sum of squares	df	Mean square	F	significant
1	regression	3717.955	1	3717.955	82.121	0.000
	residual	4119.968	91	45.274		
	total	7837.923	92			
2	regression	4526.548	2	2263.274	61.514	0.000
	residual	3311.375	90	36.793		
	total	7837.923	92			
3	regression	4749.941	3	1583.314	45.633	0.000
	residual	3087.982	89	34.696		
	total	7837.923	92			
4	regression	4918.825	4	1229.706	37.071	0.000
	residual	2919.098	88	33.172		
	total	7837.923	92			

a. dependent variable: density of transit road network (m/ha)

Figure 11. Multiple linear regression analysis between transit road density and practical factors of rural systemic risk (source: self-drawn).

Table 5. The correlation coefficient between road density and risk factors based on multiple linear regression.

Model	Non-Standardized Coefficient		Normalization Coefficient	T	Sig.
	B	Standard Error	Beta		
(Constant)	6.412	2.420		2.650	0.010
The density of the population (S_2)	0.345	0.076	0.399	4.544	0.000
The proportion of construction land (S_8)	0.101	0.034	0.280	2.986	0.004
Commuting time to and from the city (L_5)	−0.241	0.078	−0.237	−3.088	0.003
The number of primary and secondary schools within 1 km (L_2)	1.166	0.517	0.165	2.256	0.027

Source: self-created.

Meanwhile, the random forest model was used to calculate the correlation weight coefficients of each influential correlation factor relative to the density of transit roads (Table 6). The results show that the density of transit roads correlates with traffic accessibility, the proportion of construction land, ecological patch fragmentation, the proportion of farmland, population density, and other risk factors.

Table 6. Correlation weight statistics of each influential factor correlated with road density based on the random forest model.

Effective Correlation Factor	Connection Weights	Sequence
The average area of the ecological patch	10.55	3
The proportion of construction land	13.02	2
The percentage of farmland coverage	9.96	4
The percentage of ecological vegetation coverage	1.52	8
The density of the population	8.72	5
The proportion of agricultural employees	2.47	7
Commuting time to and from the city	20.58	1
The number of primary and secondary schools within 1 km	2.96	6
The number of health facilities within 1 km	0.92	9

Source: self-created.

On the basis of the analysis results of multiple linear regression and the random forest model, we determined the core correlation factors of the transit road density and analyzed the mechanism of transit traffic construction on the core risk factors. Open national, provincial, and county roads in transit transport significantly improve the accessibility of villages along the route, promoting population and the agglomeration of public facilities, helping to reduce livelihood risks and defuse industrial risks. Meanwhile, transit traffic seriously reduces rural production, living, and ecological space; aggravates the fragmentation of ecological patches; reduces ecological space resources; and intensifies ecological risks.

4.4.2. Correlation and Mechanism of Urban Employment Service Attraction and Rural Systemic Risk

Using the same process as that for the above analysis, we used SPSS Pearson correlation analysis to select the factors influencing the attractiveness of urban employment services (commuting time to urban areas) from various elements of rural systemic risk. The results show that the commuting time from a village to an urban area is significantly correlated with rural systemic risk factors, such as ecological patch fragmentation, land use structure, population change, housing vacancy, per capita cultivated land, agricultural employment, construction land change, and residents' income. Therefore, the above variable types were extracted as influential correlation factors between urban employment service attraction and rural systemic risk factors.

Multiple regression and random forest model analysis was used to explore the mechanism of the core factors of rural systemic risk related to the attractiveness of urban employment services. The results show that per capita cultivated land, per capita residential area, the proportion of construction land, and the speed of spatial change have a high correlation with the attractiveness of urban employment services. The mechanism of action is as follows: the villages with higher accessibility, made attractive by part-time employment opportunities and high-quality service facilities, have a more extensive range of population change (reduced social stability), a more vigorous demand for construction land growth, and a faster change of construction land (low ecological stability), increasing social and ecological risks. Meanwhile, with the displacement of arable land and the increase in urban population, the per capita arable land and the per the capita residential area in villages with high accessibility decline, leading to the disappearance of endogenous industries and the entry of urban non-agricultural industries, bringing great uncertainty to the development of rural industries.

4.4.3. Correlation and Mechanism between Urban Construction Land Embedding and Rural Systemic Risk Factors

Using the same analysis as the above, we screened the influential factors related to embedding urban construction land into rural areas from various elements of rural systemic risk through SPSS Pearson correlation analysis. The study shows that the proportion of urban construction land in villages is significantly correlated with ecological patch fragmentation, land use, agricultural employment, and per capita industrial land area. Therefore, the above variable types are extracted as factors influencing rural systemic risk under urban construction land embedding.

Using multiple regression and random forest model analysis, we explored the core factors of rural systemic risk related to urban construction land embedding. The results show that the embedment of urban construction land correlates with per capita industrial land, ecological patch fragmentation, the proportion of farmland, and agricultural employment. The mechanism is as follows: because of the large scale of urban construction land, rural land use has changed significantly. The increase in industrial land leads to a decrease in the proportion of farmland, the intensification of ecological patch fragmentation, an increase in the spatial change rate, and a significant increase in ecological risk. Meanwhile, the embedding of urban construction land has changed the rural industrial structure and residents' employment structure, reduced the original rural agricultural production space, and led to a decline in the proportion of agriculture. In addition, with the change in the implanted external functions, the types of non-agricultural industries will also change constantly, leading to an increase in rural industrial development and related risks.

5. Discussion

5.1. The Influence Mechanism of Urban Expansion on the Risk Resistance of Suburban Countryside

The effect of urban expansion can change suburban rural risk resistance and promote the spatial differentiation of risk resistance among villages. A glance at a summary of the effects of urban expansion on the spatial differentiation of rural risk resistance (Table 7) shows that urban expansion has no significant effect on the economic function dimension of rural risk resistance but has a strong impact on the stability and ecological sustainability dimension.

Table 7. Statistical analysis of the impact of urban expansion on spatial differentiation of rural resilience to risk.

Urban Expansion \ Dimensions of Resilience to Risk	Functional Dimension			Stability Dimension			Sustainability Dimension	
	The Affluence of the Villagers	**The Prosperity of Collective Industries**	**Diverse Employment Options**	**Ensuring People's Well-Being**	**Reasonable Labor Composition**	**Stable Land Use**	**Ecological Service Guarantee**	**Ecological Security Pattern**
The density of transit roads	Non-significant	Non-significant	Non-significant	Non-significant	Negative significance	Highly negative significance	Highly negative significance	Highly negative significance
The attraction of urban employment and services	Positive significance	Positive significance	Highly positive significance	Non-significant	Highly negative significance	Highly negative significance	Negative significance	Negative significance
The embedding of urban construction land	Non-significant	Non-significant	Negative significance	Non-significant	Negative significance	Highly negative significance	Highly negative significance	Highly negative significance

Source: self-created.

In general, the negative impact of urban expansion on the suburban rural risk resistance is dominant. The density of suburban transit roads and the embedding of urban construction land into rural space leads to a sharp drop in the ecological space resources supporting the development of rural characteristics; the pattern of ecological security is destroyed, the ecological stability and sustainability of rural risk resistance decline, and the ecological risk is prominent. The positive impact of urban expansion on rural risk resistance is that improving the spatial accessibility of suburbs leads to more industrial development and creates more employment opportunities for some villages with high accessibility, improves the income of some villagers, and improves the risk resistance from the dimension of economic function.

5.2. Influence Mechanism of Urban Expansion on the Suburban Rural Systemic Risk Factors

Urban expansion has a series of direct and indirect impacts on suburban rural systemic risk factors. The main ones are as follows: (1) The intensity of transit traffic construction directly changes the proportion of rural construction land and the rate of spatial change, and then affects the spatial differentiation of the degree of ecological space fragmentation and ecological space resources. (2) The continuous strengthening of employment service attraction in urban areas directly increases the speed of spatial change and the proportion of construction land and increases the risk of ecological space being reduced and fragmented. Meanwhile, improved industrial development and employment opportunities directly influence the differentiation of livelihood risk factors such as cultivated land and resident income, affecting the differentiation of social risk factors such as population change and housing vacancy and bringing the risk of an unstable labor structure in the rural areas. (3) The embedding of urban construction land directly increases the rate of rural spatial change, the degree of ecological space fragmentation, and ecological risks and then promotes a change in industrial risk factors such as cultivated land resources, industry, and agricultural employment (Figure 12).

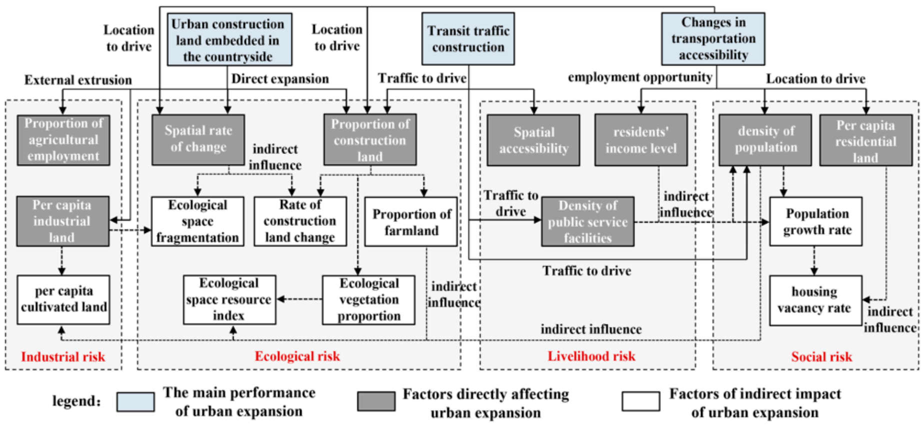


Figure 12. The influence mechanism of urban expansion on the suburban rural systemic risk factors (source: self-drawn).

Urban expansion has the maximum influence on ecological risks in suburban areas, influencing the maximum number of factors and having intensive action paths. Urban expansion mainly promotes the spatial differentiation of ecological risk factors by changing the rate of land use change and the proportion of construction land. Furthermore, along with the spatial differentiation of transportation accessibility, means of production, population and employment, public service facilities, and other factors, the spatial differentiation of industry, society, and people's livelihood between villages is deepening.

6. Conclusions

In this study, we focused on the suburban rural systemic risk under rapid urbanization in developing countries. Taking the rural areas in the western suburbs of Tianjin, China, as an example, we used multi-source data technology and spatial econometric analysis methods such as the spatial change rate model, multiple linear regression equation, and the random forest model to identify the spatial difference created by urban expansion to suburban villages. Spatial differentiation of suburban rural systemic risk elements and risk resistance was studied, and the correlation between urban expansion and spatial differentiation of rural systemic risk and its mechanism were analyzed.

The results show that the difference in urban expansion intensity is the main factor leading to the spatial differentiation of systematic risk in suburban villages. The negative impact of urban expansion on suburban rural risk resistance is dominant. The construction of suburban transportation and urban construction land embedded in rural areas has reduced ecological space resources supporting the development of rural characteristics, destroying the ecological security pattern, and reducing the stability and ecological sustainability of rural risk resistance. Among all kinds of factors of rural systemic risk, urban expansion has the most concentrated influence on ecological risk factors of suburban villages. The spatial differentiation of ecological risk factors can be promoted mainly by changing the rate of land use change and the proportion of construction land. Meanwhile, part of the rural labor force continues to be lost to urban employment, leading to the spatial differentiation of rural industrial risks and social risks increasingly aggravated.

Differentiated risk management strategies were put forward according to the effect of urban expansion and the risk characteristics of each village. For example, for villages with a high proportion of urban construction land and inefficient land consolidation, ecological restoration projects should be carried out and urban construction land should be strictly controlled in order to be implemented into villages through ecological space use control. For villages with a high density of transit roads, the spatial segmentation effect caused by transit traffic facilities should be alleviated by constructing internal roads and public transport. Meanwhile, for villages with good accessibility to urban areas and prominent concurrent employment, rural non-agricultural employment and service facilities should be precisely allocated to mitigate the impact of urban expansion on rural human resources and social structure. The above-differentiated risk management strategies of suburban villages are compatible with the spatial heterogeneity of urban expansion effect and rural risks. These strategies can provide an essential decision-making basis for formulating scientific public policy and spatial resource allocation schemes in suburban rural areas.

Author Contributions: J.T.: Conceptualization, Methodology, Data collection, Data curation, Writing—original draft preparation and editing. S.Z.: Visualization, Writing—review & editing, Funding acquisition. J.Z.: Supervision, Investigation, Writing—review & edit. S.W.: Writing—review & edit. All authors have read and agreed to the published version of the manuscript.

Funding: This study was supported by Tianjin Philosophy and Social Science Planning Project "Study on risk identification and resilience enhancement strategy of Tianjin rural industry under double cycle pattern". Grant number: TJGL21-013.

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

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Environmental Suitability Evaluation for Human Settlements of Rural Residential Areas in Hengshui, Hebei Province

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Abstract: To improve the development quality of rural residential areas in plain areas requires scientific evaluation. Based on the rural residential area in Hengshui City, Hebei Province, the study selected four indicators of location, production, ecology, and management, to build an evaluation model for the suitability of human settlements and evaluated rural residential areas in Hengshui City. The findings indicated the following: (1) The most suitable areas are mainly concentrated in the geographical center of Hengshui City. The generally suitable areas are mainly distributed in the east of the city. The basic suitable areas are scattered in the west and northeast of the city. The unsuitable areas are mainly concentrated in the north of the city. Most of the area of Hengshui City is suitable for the residence and development of rural residential areas, and 72.86% of rural residential areas are located in suitable areas, which is consistent with the geographical environment characteristics of plain areas. (2) The rural residential areas in unsuitable areas are mainly due to the low income, serious population loss and low urbanization rate, which are in line with the characteristics of rural residential areas. (3) The suitability of human settlements in rural residential areas in plain areas is mainly affected by the per capita agricultural land area, hydrology index, distance to river, distance to country, distance to a slow road, and distance to the fast road are low-level driving factors, of which distance to a fast road has the weakest influence. (4) There is a significant positive correlation between the environmental suitability and the distribution density of rural residential areas. The improvement of the suitability of human settlements can effectively promote the aggregation and distribution of rural residential areas. High-high clustering areas are mainly concentrated in the middle and northeast of Hengshui City, while low-low clustering areas are scattered in the north and southwest of Hengshui City. (5) The location index (LI) and management index (AI) play a limiting role in the suitability of human settlements in the northeast of Hengshui City, and the government should strengthen management intervention and infrastructure construction in the northeast of Hengshui City. The production index (PI) plays a limiting role in the suitability of human settlements in the west of Hengshui City and should consider the improvement of production capacity in the west of Hengshui City. The research results play a vital role in improving the carrying capacity of regional resources and the environment in the plain area, improving rural production, and living conditions, and promoting the development of rural planning in the whole region.

Keywords: rural residential areas; suitability of human settlements; suitability evaluation; Hengshui

Citation: Yu, L.; Xie, D.; Xu, X. Environmental Suitability Evaluation for Human Settlements of Rural Residential Areas in Hengshui, Hebei Province. *Land* **2022**, *11*, 2112. https://doi.org/10.3390/land11122112

Academic Editors: Carmen Delgado Viñas and María L. Gómez-Moreno

Received: 12 October 2022
Accepted: 19 November 2022
Published: 23 November 2022

1. Introduction

The spatial layout and development of human settlements are composed of the unique natural conditions of the settlements and the subjective initiative of the residents. Its main purpose is to meet the needs of the residents for survival. The research on human settlements cover landscape [1], ecology [2], climate [3], energy conservation [4], and other fields. In the 1950s, Greek planner Doxiadis first proposed the concept of human settlement science [5]. In 1961, the World Health Organization proposed "suitability" as one of the basic requirements for the construction and development of human settlements. The suitability of human settlements has become a comprehensive evaluation method for the degree of habitability, which is used to describe and evaluate the quality of human settlements scientifically and quantitatively. In studying the urban human settlements in Australia, Sri Lanka, etc., we must consider economic, traffic, and other human factors, evaluate thermal comfort [6,7], and study rural human settlements, mainly evaluating the impact of natural, climate, and other factors, on the development of rural residential areas [8,9]. With the rapid development of China in recent years, study on the suitability of the natural environment of human settlements in China found that the suitability of the natural environment for human settlements is significant [10,11] and proposed the suitability index of human settlements in arid areas [12]. Using the meteorological data of Chuxiong in recent 30 years, it was found that the meteorological index is moderate, which is conducive to improving the suitability of human settlements [13]. Based on previous studies, the suitability of human settlements can be defined as the appropriate combination degree of the following elements: climate, terrain, water and soil resources, hydrothermal conditions, atmosphere, land use, land cover, and natural disasters, all of which have an impact on human settlements [14].

The rural residential area reflects the production relationship and social culture of rural residential areas. It is a multi-disciplinary and multi-level surface space system closely related to human activities and has three functions: life, agricultural production, and non-agricultural production [15]. As a large population country, China began to formulate a dual structure of urban and rural areas in the 1950s, defining the functional positioning of urban and rural areas, respectively. The main role of rural areas is to solve food supply and other problems. Rural residential areas rely on a large number of cultivated lands to become the geographical basis for productive life activities [16]. Rural residential areas have been widely concerned by experts in geography, ecology, and sociology for a long time [14,17,18]. Mendelas, a French rural sociologist, pointed out that economic and social development, changes in family economic income, and population growth, had a significant impact on the layout of rural residential areas when summarizing the rural revival in the 1980s [19]. Nowadays, the acceleration of urbanization and industrialization has led to the tension of resources and energy and the increase of pressure on the ecological environment, which has led to changes in the security situation of the human living environment [20] and has put forward higher requirements for a series of factors, such as the surrounding natural environment, economic conditions, entertainment facilities, and convenient life [21]. It urges scholars to shift from research on the form and type of rural residential areas to research on human settlements and their suitability [22,23]. Research perspectives mainly include planning, ecology, and geography; for example, the transformation of planning methods [24], land use [25,26], ecological suitability [27], evolutionary mechanism [28,29], and suitability evaluation [30,31]. Research methods are mostly qualitative and quantitative. Based on the analytic hierarchy process (AHP) and ArcGIS technology, the minimum accumulation resistance model [32], the niche suitability model [33], the maxEnt model [34], and the multi criteria model [35], etc., are established to evaluate the suitability of rural residential areas. There are obvious regional differences in research; for example, research on rural residential areas in new residential areas in southeast Türkiye [36], and research on urban and rural land use change in Mexico [37]. The spatial differentiation of the rural residential area in the arid inland river basin is studied [38], the suitability of rural human settlements in Gansu Province is evaluated, the differentiation characteristics are clarified [39], and the suitability of rural residential areas layout in Yixing City is studied [30]. This is based on the traditional land suitability evaluation indicators, such as natural factors such as elevation, slope, and aspect [15], and location factors such as distance from roads and towns [30]. Added to this are the factors that reflect the difference of evaluation target orientation [40], and the ecological environment factors, such as land use type and vegetation coverage [27]. However, the current evaluation of the suitability of rural residential areas mainly considers the influence of elevation, slope, relief amplitude, and other topographic factors, and lacks consideration of administration factors. In addition, the number of samples for study on the suitability of rural residential areas is insufficient, especially the rural residential areas in plain areas, which are less limited by topographic characteristics and natural disasters, and are ignored due to lack of characteristics.

In recent years, the central government has issued a series of special policies to support the construction of human settlements in rural residential areas. At present, the geographical distribution of rural residential areas in the plain area is relatively scattered, and their relationship with the city cannot be as closely linked with the city as the rural areas in the coastal areas of China. The main reason is that the plain area has been constrained by the urban-rural dual structure for a long time, and is under the guidance of the development strategy of "valuing the city over the countryside". The rural residential areas in the plain area are different from other areas in improving the human settlements. While improving the human settlements, we must adhere to the issue of food security for the Chinese population [41]. Hengshui City, as a typical representative of the North China Plain, has also successively issued the Implementation Plan for Comprehensively Promoting Rural Human Settlements Improvement [42], trying to provide a good living environment for rural residential areas. However, the problems of "rural diseases", such as extensive land use, single function, lack of planning, hollowing, and poverty, which have been formed in rural residential areas for a long time, are becoming more and more serious [43]. The key to rural revitalization is livability, and the suitability evaluation of settlement is the prerequisite for rural renovation, optimization and reconstruction, and the improvement of human settlements [23]. Therefore, based on the scientific and objective suitability evaluation results, and based on the actual development of regional settlements, research on the suitability of human settlements has become key to solving these problems.

Based on the above analysis, this study: establishes a suitability evaluation model based on the AHP method; selects four indicators of location, production, ecology, and administration to evaluate the suitability of rural residential area in Hengshui City; clarifies the geographical and spatial relationship between various indicators and rural residential area; and clarifies the relationship between rural residential area in the appropriate areas and various factors, so as to provide new ideas for the optimization and improvement of settlement and the improvement of human settlements.

2. Research Scope and Data Sources

2.1. Overview of the Study Area

Hengshui City is in the southeast of Hebei Province. The land scope is 115°10′–116°34′ east longitude and 37°03′–38°23′ north latitude. The city size is 98.13 km wide from east to west and 125.25 km long from south to north (Figure 1). It belongs to Hebei Plain, with flat terrain, the elevation difference of the whole area shall not exceed 25 m, 9 rivers in total, and a continental monsoon climate. It belongs to the Bohai Rim Economic Circle and the Capital Economic Circle. It is dominated by agriculture. The total land area of the city is about 8836.78 km^2, of which farmland accounts for about 65% of the land area. The total lighting hours throughout the year are 2609.9 h, and the average precipitation over the years is 524.2 mm. By the end of 2021, Hengshui has a population of 4.589 million, the agricultural population accounts for more than 80% of the total population governing two municipal districts, one county-level city, and eight counties. The rural residential area of the city is 97,368 hectares, accounting for 11.02% of the city's land area. The number of rural residents is large, but the scale is small. The rural production base is difficult to adapt to the requirements of modern agricultural mechanization and large-scale production, resulting in low land production efficiency and urgent need to improve agricultural production conditions.

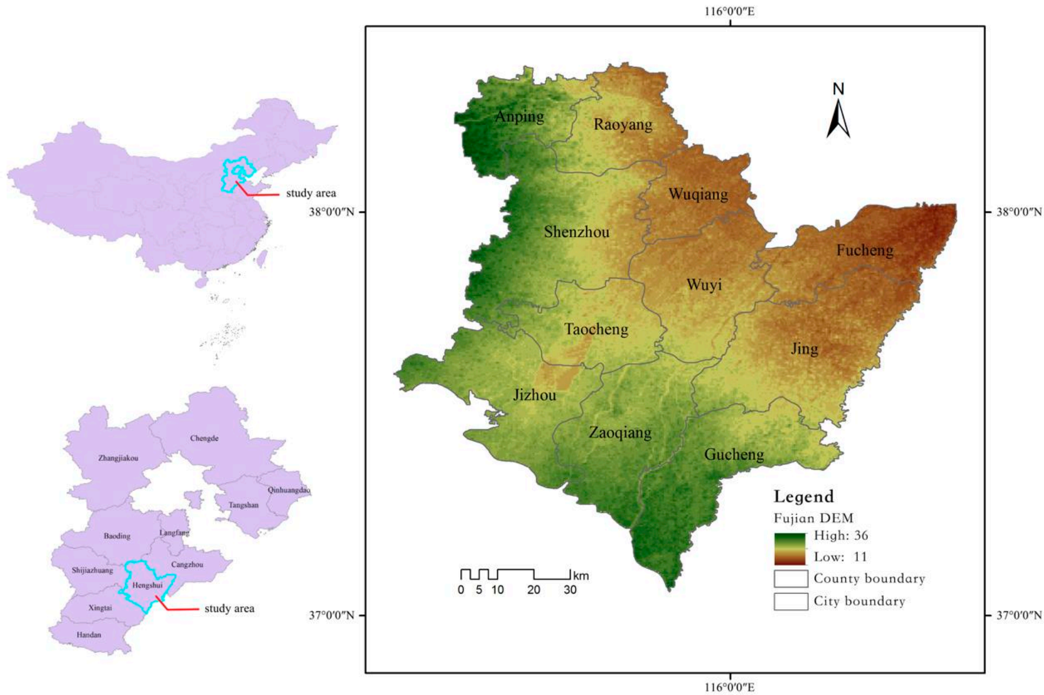

Figure 1. Geographic location map of Hengshui city.

2.2. Data Sources and Processing

Rural residential areas are represented as point elements on the macroscopic scale. Therefore, in the study, the spatial coordinates of rural residential areas are used to replace the rural residential area with a certain regular shape. The detailed directory and relevant data of 4911 rural residential areas were obtained through field research and retrieval of the Hengshui Municipal Planning and Natural Resources Bureau website. On this basis, the POI (Points of Interest) spatial location of each rural residential area in the Baidu map was obtained with the help of the Geosharp software for positioning and coordinate picking (the coordinate picking point is subject to the location of the rural residential area committee, accessed on July 2022).

The selected data include land use data, socio-economic statistics, digital elevation data, planning data, and interest point data, with specific names and sources (Table 1). These parameters were gathered from various sources and are processed and converted into raster data of 30 × 30 m for convenient handling using the ArcMap 10.8 software.

Table 1. Data and data sources.

Category	Remarks	Data Source	Date	Source Location
Distance to fast road	It reflects the development degree of external transportation and represents the convenience of connecting in rural residential areas and cities. The shorter the distance, the better [5].	National Geographic Information Resources Directory Service System	accessed on 2 June 2022	https://www.webmap.cn/

Table 1. *Cont.*

Category	Remarks	Data Source	Date	Source Location
Distance to slow road	It reflects the development degree of external traffic and represents the convenience of traffic in rural residential areas. The shorter the Euclid distance, the better [44].	National Geographic Information Resources Directory Service System	accessed on 2 June 2022	https://www.webmap.cn/
Distance to County	Reflecting geographical position and Convenience of life [20].	National Geographic Information Resources Directory Service System	accessed on 2 June 2022	https://www.webmap.cn/
Distance to river	Reflecting water resources condition [20].	Resource and Environmental Science Data Center	accessed on 5 November 2021	https://www.resdc.cn/
Population of the county	Reflect the economic production capacity of the region [30].	Hengshui statistical yearbook 2020	accessed on 7 November 2021	http://www.shujuku.org/
Urbanization degree	Reflecting the process of urbanization, it is usually expressed as the percentage of the urban population in the total population, which is used to reflect the process and degree of population gathering in the city. The higher the degree of urbanization, the stronger the productivity [30].	Hengshui statistical yearbook 2020	accessed on 7 November 2021	http://www.shujuku.org/
Non-agricultural industry degree	The ratio of the population engaged in secondary and tertiary industries to the total population, Reflects the regional employment structure [31].	Hengshui statistical yearbook 2020	accessed on 15 April 2022	http://www.shujuku.org/
Per capital income of farmers	Reflecting the average income level of rural residents in a region [14].	Hengshui statistical yearbook 2020	accessed on 15 November 2021	http://www.shujuku.org/
Hydrology Index (HI)	Reflect the optimization of land use structure. More construction can be carried out to improve the public living environment [38].	Geographic remote sensing ecological network platform	accessed on 11 May 2022	http://www.gisrs.cn/
Vegetation coverage	Reflect the optimization of land use efficiency and ecological environment suitable for human habitation [37].	Resource and Environmental Science Data Center	accessed on 11 May 2022	https://www.resdc.cn
Temperature Humidity Index (THI)	It reflects the development degree of external transportation and represents the convenience of connecting in rural residential areas and cities. The shorter the distance, the better [38].	Geographic remote sensing ecological network platform	accessed on 11 July 2022	http://www.gisrs.cn/
Proposed development proportion of construction land	It reflects the development degree of external traffic and represents the convenience of traffic in rural residential areas. The shorter the Euclid distance, the better [5].	Hengshui city land acquisition development plan (2021–2023) (Draft for comments)	accessed on 8 July 2022	http://zrgh.hengshui.gov.cn/
Per capita agricultural land area	Reflecting geographical position and Convenience of life [18].	Hengshui city land acquisition development plan (2021–2023) (Draft for comments)	accessed on 8 July 2022	http://zrgh.hengshui.gov.cn/

2.3. Research Framework

The suitability of rural residential areas in Hengshui City is analyzed by establishing an evaluation model for the suitability of human settlements. The basic principles are as follows: first, screen out the main factors that affect rural residential area, establish a suitability evaluation system, determine the weight of each factor using the AHP, then assign values to the grading of these impact factors through expert scoring, and use the ArcMap10.8 software to grid the data. Using the layer overlay analysis function, the grid map of each factor is weighted and superimposed to obtain the comprehensive evaluation results of the suitability of human settlements suitability. On this basis, it is superimposed with the rural residential geographic space points and graded to determine the characteristics of human settlements' suitability. Its research route is shown in Figure 2.

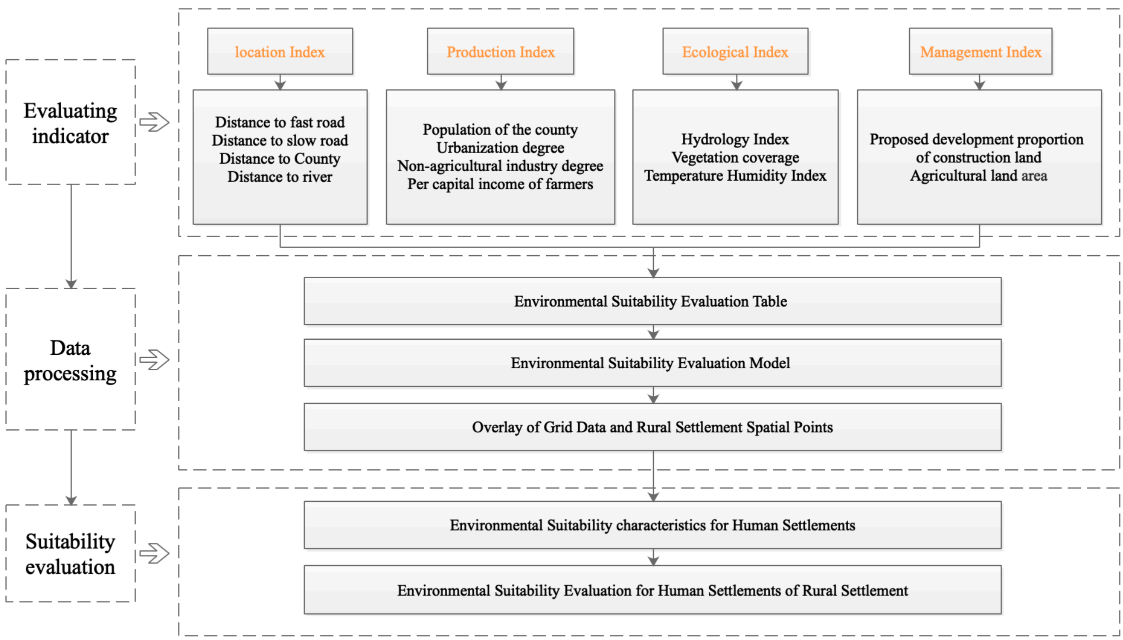

Figure 2. Research flow chart.

3. Research Methodology and Experiments

3.1. Human Environment Suitability Index Model (HEI Model)

In this paper, the suitability evaluation model of human settlements is used to evaluate the suitability of rural residential areas in Hengshui. The purpose is to give corresponding weights to different factors in a fuzzy environment with multiple determining factors, and finally give a relatively scientific comprehensive evaluation result to the evaluation object. The specific formula is as follows:

$$HEI = \alpha \times NLI + \beta \times NPI + \gamma \times NEI + \delta \times NMI \quad (1)$$

where *HEI* is the Human Settlements Environment Index. *NLI* is the normalized *LI*, *NPI* is the normalized *PI*, *NEI* is the normalized *EI*, *NMI* is the normalized *MI*. α, β, γ, and δ, respectively, represent the weight of four indexes.

3.2. AHP-Weighted Information Content Method

(1) Construct judgment matrix *A* (orthogonal matrix), and use a_{ij} represents the comparison result of the *i* factor with respect to the *j* factor:

$$A = (a_{ij})_{n\times n} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \tag{2}$$

(2) Geometrically average the vectors in each row of matrix *A* (square root method), and then normalize them to obtain the weight of each evaluation index and the eigenvector *W*:

$$W_i = \overline{W}_i / \sum_{i=1}^{n} \overline{W}_i, \quad W = \begin{Bmatrix} W_1 \\ W_2 \\ \vdots \\ W_n \end{Bmatrix} \tag{3}$$

(3) Consistency test, *CI* = 0, with complete consistency, *CI* is close to 0, with satisfactory consistency, The larger the *CI*, the more serious the inconsistency:

$$CI = \frac{\lambda_{max} - n}{n-1} \tag{4}$$

where λ Is the maximum characteristic root, N is the unique non-zero characteristic root. To measure the size of *CI*, *CR* is used to define the consistency ratio, the formula is as follows:

$$CR = \frac{CI}{RI} \tag{5}$$

where *RI* is a random consistency index. when the consistency ratio $CR < 0.1$, it is considered that the degree of A's inconsistency is within the allowable range, and there is satisfactory consistency, which passes the consistency test.

3.3. Geographical Detector (GeoDetector)

The Geodetector is one of the powerful tools for scholars to carry out driving force and factor analysis at present, which can detect both numerical data and determinative data [45]. The influence of each factor on suitability can be quantified by statistical analysis of the superposition results of factors and suitability. The influence of each factor is measured by q value, and the algorithm is as follows:

$$\mathrm{q} = 1 - \frac{\sum_{h=1}^{L} N_h \sigma_h^2}{N\sigma^2} = 1 - \frac{SSW}{SST} \tag{6}$$

where h = 1,2 … … , L is the stratification of variable *Y* or detection factor *X*, i.e., classification or partition, σ^2 and σ_h^2 is the variance of the whole region *Y* value and layer h respectively, *N* and N_h is the unit number of the whole area and layer h, respectively, *SST* is the total variance of the whole region, *SSW* is the sum of variance within the layer, and the range of q value is [0~1]. The larger the q value is, the stronger the influence of the detection factor on the suitability is otherwise, the weaker the influence is.

3.4. Coefficient of Geographic Association

The coefficient of geographic association can reflect the matching between two geographical activities or elements in the region [46]. The difference in similarity reflects the difference in spatial structure, which can be used to express the overall spatial connection level of rural residential distribution and suitability. The formula is as follows:

$$GL = 100 - \frac{1}{2}\sum_{i=1}^{n}|S_i - P_i| \quad (7)$$

where *GL* refers to the geographic connection rate between the distribution and suitability of rural residential area, *N* is the number of units, S_i and represents the percentage of the element values of each field in Region I, respectively. The higher the *GL* value is, the closer the geographical relationship between the two is and the more consistent the geographical distribution is.

3.5. Bivariate Spatial Autocorrelation

Bivariate spatial autocorrelation has high effectiveness and applicability when Moran's I is used to describe the relationship between two geographical things, including global spatial autocorrelation and local spatial autocorrelation [46]. It can be used to describe the spatial consistency and correlation between rural residential areas and suitability. The formula is as follows:

$$I = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}(x_i - \overline{x})(y_j - \overline{y})}{\sigma^2 \sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}} \quad (8)$$

where *I* is the spatial correlation strength of two types of geographic transactions, x_i and represent transaction *i* and *j* respectively, *N* is the number of units, σ^2 is the sample variance, w_{ij} is the spatial weight matrix. When $I = 1$, there is an absolute spatial correlation between them, when $I = -1$, there is absolute dispersion, when $I = 0$, it indicates random distribution.

3.6. Establishment of HEI Model

3.6.1. Establish Evaluation Index System

Rural residential areas are comprehensively affected by nature geography, social economy, and other factors. According to the principle of AHP, the evaluation index system is reasonably divided into the following three different levels: in the first level, the target level refers to the general objective of the suitability evaluation of rural residential areas; in the second level, the criteria level mainly includes four aspects, namely, location index (LI), production index (PI), ecological index (EI), and management index (MI); in the third level, the indicator layer is, respectively: distance to a fast road, distance to a slow road, distance to county, distance to river, population of the country, urbanization degree, non-agricultural industry degree, per capita income of farmers, hydrology index (HI), vegetation coverage, temperature humidity index (THI), the proposed development proposal of construction land, and agricultural land area. Based on the domestic and international suitability of human settlements suitability evaluation studies, this study classifies and summarizes various evaluation elements, and constructs Hengshui City's suitability of human settlements suitability evaluation index system (Figure 3) according to the hierarchical relationship, including four first-degree indicators and 13 s-degree indicators.

3.6.2. Establish Suitability Evaluation Index Table

Based on the division of the target layer, middle layer, and indicator layer in the suitability indicator system, the relative importance and intensity relationship of each impact factor are determined by expert scoring, and the pairwise judgment matrix of the target layer, middle layer, and indicator layer is constructed. The YaAHP software is used to calculate the weight of factors at this level to the factors at the next level and combined with the impact trend of each factor on the suitability of rural residential areas, each factor grading is assigned by 0~9 to generate the evaluation table of suitability indicators for rural residential areas (Table 2).

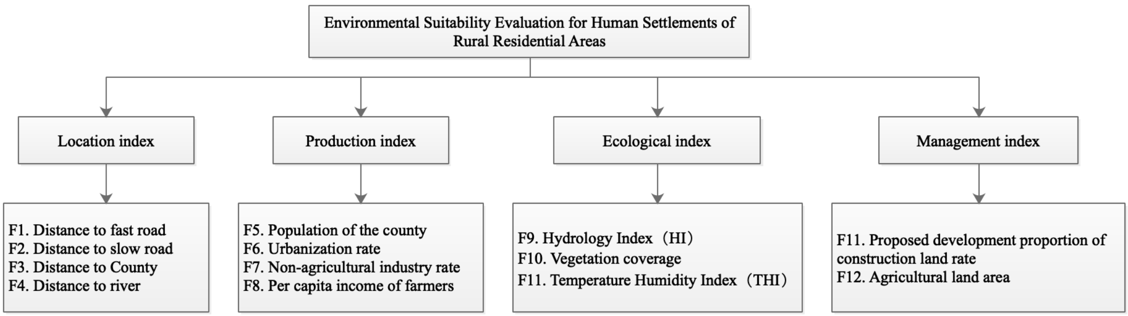

Figure 3. Evaluation index system of rural residential suitability.

Table 2. Table of suitability evaluation indicators.

Middle Layers	Weight	Indicators	Weight	Factor Classification	Value
location index	0.1756	Distance to fast road (km)	0.0298	<5	9
				5~10	7
				10~15	5
				15~20	3
				>20	1
		Distance to slow road (km)	0.0419	<1	9
				1~2	7
				2~3	5
				3~4	3
				>4	1
		Distance to County (km)	0.0693	<8	9
				8~16	7
				16~24	5
				24~32	3
				>32	1
		Distance to river (km)	0.0346	<2	9
				2~5	7
				5~10	5
				10~15	3
				>15	1
Production index	0.2887	Population of the county (k)	0.0407	>477	9
				418~477	7
				370~418	5
				315~370	3
				<315	1
		Urbanization rate (%)	0.0813	>70.0	9
				59.6~70.0	7
				51.5~59.6	5
				47.6~51.5	3
				<47.6	1
		Non-agricultural industry rate	0.0693	>86.1	9
				82.5~86.1	7
				79.3~82.5	5
				74.2~79.3	3
				<74.2	1
		Per capital income of farmers (k)	0.0974	>30.9	9
				28.6~30.9	7
				27.2~28.6	5
				25.6~27.2	3
				<25.6	1

Table 2. *Cont.*

Middle Layers	Weight	Indicators	Weight	Factor Classification	Value
Ecological index	0.247	Hydrology Index	0.081	>0.54	9
				0.47~0.54	7
				0.40~0.47	5
				0.33~0.40	3
				<0.33	1
		Vegetation coverage (hm^2)	0.0645	> 35,400	9
				28,400~35,400	7
				23,100~28,400	5
				17,900~23,100	3
				<17,900	1
		Temperature Humidity Index	0.1016	>89.5	9
				88.7~89.5	7
				87.7~88.7	5
				86.6~87.7	3
				<86.6	1
Management index	0.2887	Proposed development proportion of construction land rate (%)	0.1443	>24.6	9
				19.6~24.6	7
				16.7~19.5	5
				14.0~16.7	3
				<14.0	1
		Agricultural land area (hm^2)	0.1443	>63,700	9
				55,900~63,700	7
				48,300~55,900	5
				40,200~48,300	3
				<40,200	1

4. Results

4.1. Human Environmental Suitability Characteristics

According to the suitability evaluation model, the suitability of human settlements in rural residential areas of Hengshui City is quantitatively analyzed. With the help of the inverse distance weight interpolation function in the ArcMap10.8 software, the data of each factor is rasterized, and the grid map of each factor is weighted and superposed to form the suitability evaluation grid surface map of rural residential areas (Figure 4). It can be seen from the figure that the suitability range of rural residential area is 2.3712~7.3922, and the high value is in the geographical center of Hengshui City.

4.2. Classification of the Suitability of Rural Residential Area

In order to clarify the suitability differences between the whole study area, and facilitate the subsequent provision of corresponding protection strategies, the suitability grade zoning of rural residential areas is delineated. The natural discontinuity method is used to classify the suitability range to form the threshold value of the suitability level (Table 3). The suitability classification map of rural residential areas is generated based on the grid map of the suitability evaluation of rural residential areas with threshold values (Figure 5). The results show that there are obvious differences between the most suitable and unsuitable regions: (1) The most suitable area is mainly concentrated in the geographical center of Hengshui City, where the agricultural land use rate is high, the proportion of construction land to be developed is high, the vegetation coverage area is large, and the non-agricultural industry rate is high. This region provides better policy guidance for residents. (2) The generally suitable area is mainly distributed in the east of Hengshui City, and the agricultural land use rate in this region is next to the most suitable region. The temperature and humidity index, hydrological index, and plant coverage rate, are relatively high, which can provide more comfortable climatic conditions and ecological environment for residents. (3) The basic suitable areas are scattered in the west and northeast of Hengshui City, with convenient transportation and good unknown conditions. (4) Unsuitable areas are mainly concentrated in the north of Hengshui City, with a small population, urbanization rate, income, temperature, humidity index, and hydrological index, lower than in other areas.

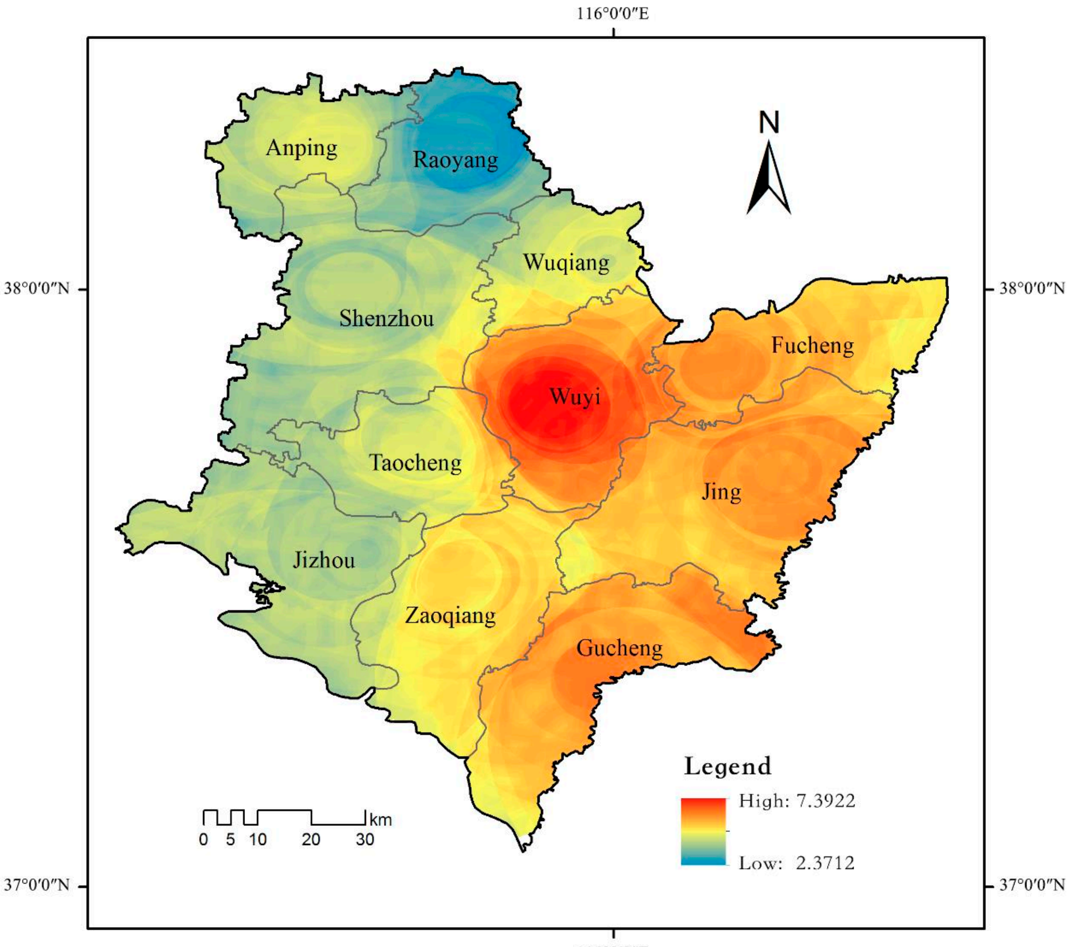

Figure 4. Suitability evaluation grid surface map.

Table 3. Classification standard for suitability evaluation of rural residential areas.

Grade	Threshold Value Division	Suitability Zoning
Grade I suitable area	2.3712–3.7930	Unsuitable
Grade II suitable area	3.7930–4.8796	Basically suitable
Grade III suitable area	4.8796–5.8856	Generally suitable
Grade IV suitable area	5.8856–7.3922	Most suitable

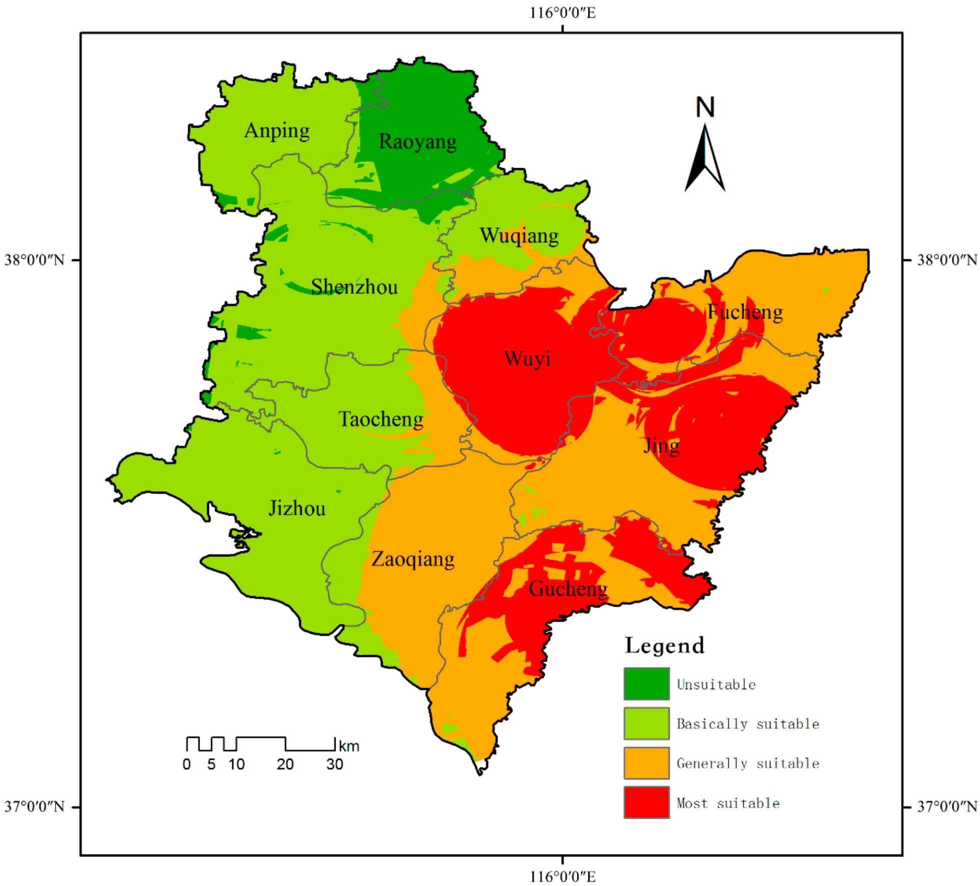

Figure 5. Suitability classification diagram.

The map algebra method is used to calculate the element values of each grid unit and obtain the suitability classification statistical table of rural residential areas (Table 4). The results show that: (1) The suitable area accounts for 7.01%, and 4.44% of rural residential areas are distributed in this area. (2) The general suitable area accounts for 39.42%, and 31.25% of rural residential areas are distributed in this area. (3) The area of the basically suitable area accounts for 31.96%, and 37.17% of the rural residential area are distributed in this area. (4) The area of unsuitable areas accounts for 21.61%, and 27.14 rural bureau settlements are distributed in this area. In general, 78.39% of the area of Hengshui City is suitable for the residence and development of rural residential areas, and 72.86% of rural residential areas are in suitable areas.

Table 4. Statistical results of suitability classification of the rural residential areas in Hengshui.

Grade	Percentage of Area	Number of Villages	Percentage of Numbers
Grade I suitable area	7.01%	218	4.44%
Grade II suitable area	39.42%	1535	31.25%
Grade III suitable area	31.96%	1826	37.17%
Grade IV suitable area	21.61%	1333	27.14%

4.3. The Difference in Suitability Distribution of County-Level Units

There are differences in the suitability of rural residential areas in the study area. Analysis under the restriction of administrative divisions is conducive to finding the reasons for the suitability differences. According to the municipal administrative divisions, the suitability of ethnic minority villages was analyzed by level (Table 5). The results show that the rural residential areas in Wuyi County and Jingxian County are the most suitable for living. A total of 33.31% and 32.41% of the rural residential areas are in the most suitable area; 4.55% and 23% of the rural residential areas are in the general suitable area; and no rural residential areas are in the unsuitable area. The rural residential area in Fucheng County and Gucheng County are also relatively suitable for living. In all, 15.15% and 18.75% of the rural residential area are in the most suitable area, respectively, and 22.29% and 15.5% of the rural residential area are in the general suitable area. The rural residential area in Jizhou County, Taocheng County, Wuqiang County, and Zaoqiang County are basically suitable for living. All rural residential areas are in general suitable areas and basically suitable areas, and no rural residential area are in unsuitable areas. Anping County, Raoyang County, and Shenzhou County, all have rural residential areas located in unsuitable areas, among which Raoyang County has the largest number, and 84.86% of the rural residential area are in unsuitable areas, mainly due to low income, serious population loss, and low urbanization rate.

Table 5. Statistics on the suitability of rural settlement in each county.

County	Numbers	Percentage	Percentage of Rural Residential Areas in Each Suitability Level			
			Grade I	Grade II	Grade III	Grade IV
Anping	246	5.01%	4.59%	15.38%	0.00%	0.00%
Fucheng	610	12.42%	0.00%	0.07%	22.29%	15.15%
Gucheng	538	10.95%	0.00%	0.33%	15.50%	18.75%
Jizhou	390	7.94%	0.00%	25.42%	0.00%	0.00%
Jing	856	17.43%	0.00%	0.26%	23.00%	32.41%
Raoyang	200	4.07%	84.86%	0.98%	0.00%	0.00%
Shenzhou	469	9.55%	10.55%	26.73%	1.97%	0.00%
Taocheng	272	5.54%	0.00%	15.91%	1.48%	0.08%
Wuqiang	242	4.93%	0.00%	9.39%	5.37%	0.00%
Wuyi	528	10.75%	0.00%	0.07%	4.55%	33.31%
Zaoqiang	560	11.40%	0.00%	5.48%	25.85%	0.30%

5. Discussion

5.1. Correlation between Impact Factors and Suitability of Human Settlements

The factor detector of GeoDetector is used to analyze the correlation between each factor and suitability, quantify the influence of each factor on suitability (q value), and use the interaction detector to test the interaction influence of each factor. The suitability value of each element unit is selected as the dependent variable, and each factor is the independent variable.

According to the factor detection results (Table 6), the environmental suitability of rural settlement in Hengshui City is significantly affected by various factors. The specific order is per capita agricultural land area > vegetation coverage > population of the county > per capita income of farmers > construction land rate > temperature humidity index > non-agricultural industry rate > urbanization rate > hydrology index > distance to river > distance to county > distance to slow road > distance to fast road. Among them, per capita agricultural land area has the highest influence, which is 0.702. This shows that the suitability of the rural residential environment is mainly affected by the area of per capita agricultural land. The level of specialization and modernization of agricultural production has been improved, farmers have developed towards professionalism, and have relatively rich cultivated land resources, providing favorable conditions for the layout of rural residential areas [47,48]. The residential environment of rural residential areas in hilly areas is mainly affected by rivers, elevations, and slopes [33]. The influence values of HI, distance to river, distance to county, distance to slow road, and distance to fast road, are 0.097, 0.015, 0.010, 0.009, and 0.004, respectively, which are less than 0.1, indicating that they are low-level driving factors, of which distance to fast road has the weakest influence.

Table 6. Impact factor detection analysis table.

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13
q	0.004	0.009	0.010	0.015	0.542	0.132	0.137	0.364	0.097	0.655	0.305	0.330	0.702
p	0.012	0.008	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

It can be seen from the factor interaction detection results (Table 7) that the relationship between factors is double factor enhancement, and there is no nonlinear enhancement, independence, or weakening relationship. The interaction influence of per capita agricultural land area and hydrology index is significantly enhanced, which is significantly higher than the influence of single factor per capita agricultural land area of 0.702 and the influence of single factor hydrology index of 0.097. Based on existing research, this study did not include elevation, slope, and aspect in the evaluation index of human settlements suitability in rural residential areas in plain areas, and the interaction effect of two factors was significantly enhanced. The research improves the rationality and scientific of the evaluation results, improves the evaluation system, and can provide reference for the suitability evaluation of other rural residential areas.

Table 7. Interaction analysis table of impact factors.

——	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13
F1	0.004	——	——	——	——	——	——	——	——	——	——	——	——
F2	0.020	0.009	——	——	——	——	——	——	——	——	——	——	——
F3	0.029	0.023	0.010	——	——	——	——	——	——	——	——	——	——
F4	0.026	0.033	0.049	0.015	——	——	——	——	——	——	——	——	——
F5	0.574	0.548	0.635	0.559	0.542	——	——	——	——	——	——	——	——
F6	0.141	0.157	0.212	0.165	0.692	0.132	——	——	——	——	——	——	——
F7	0.161	0.155	0.238	0.208	0.651	0.397	0.137	——	——	——	——	——	——
F8	0.395	0.387	0.464	0.412	0.703	0.471	0.489	0.364	——	——	——	——	——
F9	0.131	0.118	0.165	0.208	0.786	0.431	0.387	0.563	0.097	——	——	——	——
F10	0.674	0.661	0.710	0.703	0.760	0.680	0.811	0.809	0.859	0.655	——	——	——
F11	0.335	0.337	0.374	0.334	0.861	0.540	0.627	0.616	0.520	0.847	0.305	——	——
F12	0.345	0.353	0.409	0.355	0.745	0.614	0.556	0.663	0.488	0.789	0.603	0.330	——
F13	0.717	0.710	0.761	0.741	0.775	0.745	0.799	0.836	0.861	0.762	0.848	0.836	0.702

5.2. The Spatial Relationship between the Suitability of Human Settlements and Rural Residential Areas

In rural China, settlements are usually located near farmland for convenient agricultural production [49]. The GeoDa1.20 software is used to analyze the suitability of human settlements and the distribution density of rural residential areas, and the geographic connection rate between them reaches 96.34, indicating that there is a high degree of mutual connection and interaction between them. From the perspective of global spatial autocorrelation (Figure 6), the bivariate Moran's I index of the suitability of human settlements and the distribution density of rural residential areas is 0.513, and the p value is less than 0.01, indicating that there is a significant positive correlation between them. The improvement of the suitability of human settlements can effectively promote the aggregation and distribution of rural residential areas.

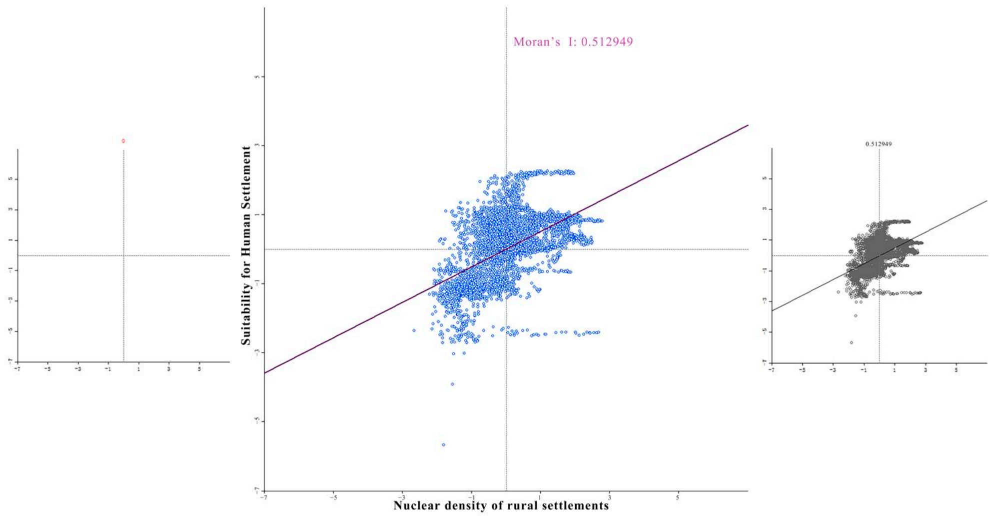

Figure 6. Spatial global autocorrelation.

The suitability of human settlements is spatially related to the distribution density of rural residential areas. As can be seen from Figure 7, the *p* values of several regions are less than 0.05, indicating that all spatial distribution patterns are unlikely to be generated from random processes. The high-high cluster areas of the suitability of human settlements suitability and rural residential distribution density are mainly concentrated in the middle and northeast of Hengshui City. The suitability of human settlements and rural residential distribution density in these areas are both high, and they show a significant interaction. Low-low cluster areas are scattered in the north and southwest of Hengshui City. The suitability of human settlements and the distribution density of rural residential areas in these areas are both low, showing a significant interaction between them. The supporting and leading role of the suitability of human settlements in rural residential areas need to be further strengthened. High-low concentration areas are mainly concentrated in the east of Hengshui City, with a large area, relatively high density of rural residential areas, but relatively low suitability of human settlements. Low-high cluster areas are mainly distributed in the east and southeast of Hengshui City. The density of rural residential areas in these areas is relatively low, but the suitability of human settlements is relatively high.

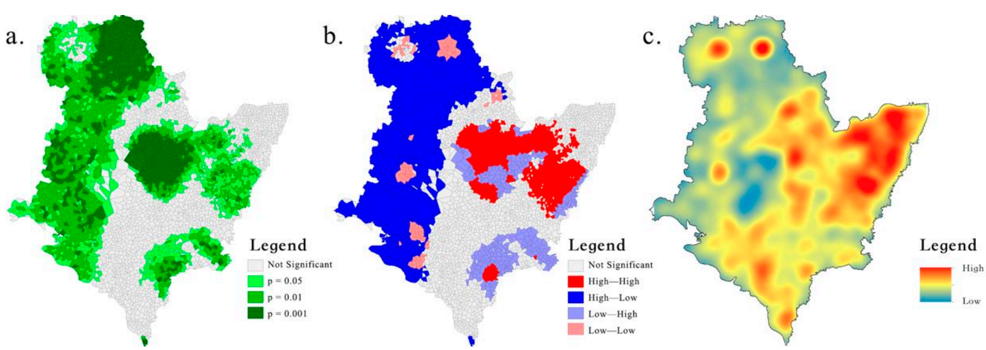

Figure 7. LISA cluster diagram of the spatial correlation between the suitability of human settlements and the distribution of rural residential areas: (**a**) Local autocorrelation *p* value distribution map; (**b**) local autocorrelation cluster diagram; (**c**) nuclear density map of rural residential areas.

5.3. Differentiation of Suitability Evaluation of Human Settlements

Superposition the single factors in LI, PI, EI, and MI to obtain the suitability distribution map of the middle layer indicators LI, PI, EI, and MI, and compare it with the suitability distribution map of human settlements; it can be found that they have a high degree of similarity and fusion (Figure 8). In the study of rural residential areas in hilly areas, the slope, orientation, and undulation of terrain factors are added to the study. The final result is that rural residential areas are most affected by the terrain, but this result is not applicable to plain areas [31].

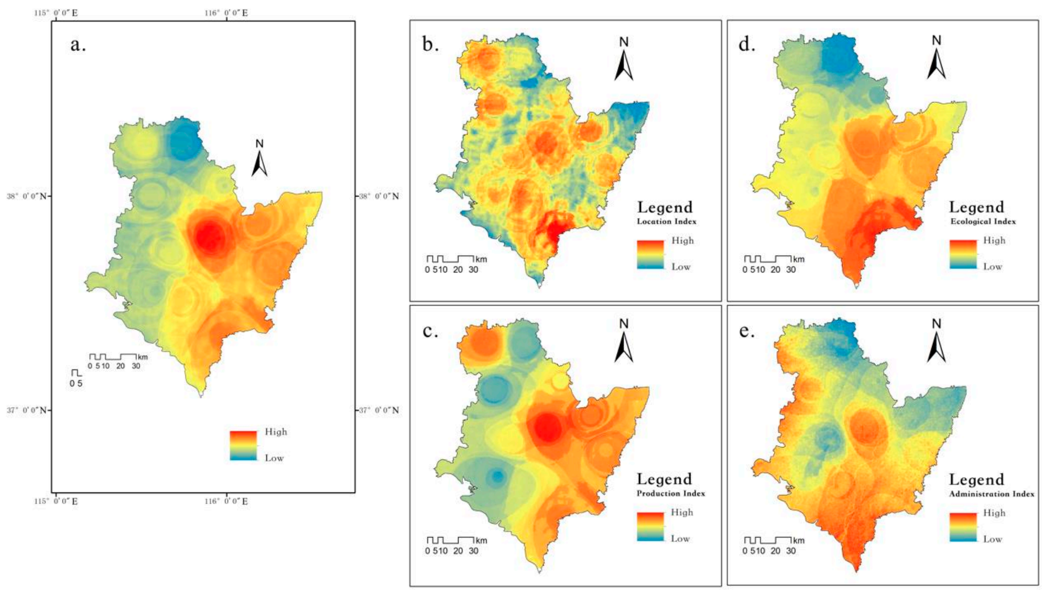

Figure 8. Spatial comparison between the middle layer index suitability distribution map and the human settlements suitability distribution map: (**a**) the human settlements suitability distribution map; (**b**) location index suitability distribution map; (**c**) production index suitability distribution map; (**d**) ecological index suitability distribution map; (**e**) administration index suitability distribution map.

LI, PI, EI, and MI are high in the most suitable area for human settlements. The human settlement environment is generally suitable for the region. The PI and EI are high, while the LI and MI play a certain role in limiting the suitability of the human settlement environment in the northeast of Hengshui City. The government should strengthen the intervention in this region and strengthen the infrastructure in this region, The value of the LI is higher in the northwest of Hengshui City, the MI is higher in the west, and PI is higher in the northwest of Hengshui City, and PI is lower in the west. PI plays a certain role in limiting the suitability of human settlements, so we should pay attention to the intervention of production in Hengshui City. The values of the four indexes are low in unsuitable areas, so administrative intervention should be strengthened in this area to improve production efficiency, increase infrastructure, and strengthen ecological protection.

The rural residential area is a choice made by human beings in the long-term production and living practice process, which adapts to and interacts with many factors such as nature and society. This study is based on one year's data, and little consideration is given to the evolution process of rural residential areas. At the same time, when evaluating the suitability of the residential environment of rural residential areas, the impact of humanity and farmers' wishes is ignored. The shortcomings of the study will be further discussed in the future.

6. Conclusions

(1) The most suitable area is mainly concentrated in the geographical center of Hengshui City, accounting for 7.01% of the total area. In all, 4.44% of the rural residential areas are distributed in this area. The general suitable area is mainly distributed in the east of Hengshui City, accounting for 39.42% of the total area. Totaling 31.25% of the rural residential areas are distributed in this area, the basic suitable areas are scattered in the west and northeast of Hengshui City, accounting for 31.96% of the area, and 37.17% of the rural residential areas are distributed in this area. Unsuitable areas are mainly concentrated in the north of Hengshui City, accounting for 21.61% of the area. In all, 27.14 rural bureau settlements are distributed in this area. In general, 78.39% of the area of Hengshui City is suitable for the residence and development of rural residential areas, and 72.86% of rural residential areas are in suitable areas. From the perspective of spatial distribution and the quantity of rural residential areas, the distribution of suitable rural residential areas conforms to the geographical environment characteristics of plain areas.

(2) Wuyi County and Jingxian County have the most livable rural residential areas; Raoyang County has the most uninhabitable rural residential areas. The rural residential area is located in an uninhabitable area, mainly because of its low income, serious population loss, and low urbanization rate.

(3) The suitability of human settlements in rural residential areas is mainly affected by per capita agricultural land area, with the highest influence value of 0.702. The influence values of HI, distance to river, distance to county, distance to slow road, and distance to fast road are 0.097, 0.015, 0.010, 0.009, and 0.004, respectively, which are less than 0.1, indicating that they are low-level driving factors, of which distance to fast road has the weakest influence. These factors provide reference for the establishment of the evaluation system of the suitability of human settlements in rural residential areas in plain areas.

(4) The high-high cluster areas of human settlement suitability and rural residential distribution density are mainly concentrated in the middle and northeast of Hengshui City. Low-low cluster areas are scattered in the north and southwest of Hengshui City, and the supporting and leading role of the suitability of human settlements in rural residential areas need to be further strengthened. High-low concentration areas are mainly concentrated in the east of Hengshui City, with a large area, relatively high density of rural residential areas, but relatively low suitability of human settlements. The low-high cluster areas are mainly distributed in the east and southeast of Hengshui City. The suitability of human settlements in these areas is relatively high, but the density of rural residential areas is relatively low. It shows that the evaluation model is suitable for the study of the suitability of rural residential areas in plain areas, and there is a significant positive correlation between the suitability of human settlements and the distribution density of rural residential areas. The improvement of the suitability of human settlements can effectively promote the aggregation and distribution of rural residential areas.

(5) LI and MI have a certain impact on the suitability of human settlements in the northeast of Hengshui City, and we should strengthen management intervention and infrastructure construction in the northeast of Hengshui City. The PI plays a limiting role in the suitability of human settlements in the west of Hengshui City, and we should pay attention to the improvement of production capacity in the west of Hengshui City. We should strengthen management intervention in the northwest of Hengshui City, improve production efficiency, increase infrastructure, and strengthen ecological protection.

Author Contributions: Conceptualization, L.Y. and D.X., methodology, L.Y. and X.X.; software, X.X.; validation, X.X.; formal analysis, L.Y. and X.X.; investigation, L.Y. and D.X.; resources, L.Y.; data curation, L.Y.; writing—original draft preparation, L.Y., D.X. and X.X.; writing—review and editing, D.X. and X.X.; visualization, X.X.; supervision X.X. and D.X.; contact author, X.X.; project administration, D.X. and X.X.; funding acquisition, L.Y. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Henan Science and Technology Development Plan Project, project number:212102310956.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study, in the collection, analyses, or interpretation of data, in the writing of the manuscript, or in the decision to publish the results.

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Article

Urban Rural Interaction: Processes and Changes in the *Marina Oriental* of Cantabria (Spain)

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Abstract: Since the middle of the last century, especially since the seventies, processes have been generated and consolidated that have changed the image of certain rural environments in Spain, especially coastal, with new forms of organization and territorialities that break the traditional model. The Cantabrian territory, like other areas of the Spanish coast, has seen its territories and landscapes altered in terms of its demographic, economic, and urban structures. The variation over the easternmost area of the Autonomous Community of Cantabria is significant, affected by various growth processes of both cities in the region, as well as others adjacent and connected, such as the urban agglomeration of Bilbao, influencing this space that we call *Marina Oriental* de Cantabria. The justification and objectives are to know how the coastal geographical situation, good communications, and proximity to Bilbao have configured this space to become a functional part of the metropolitan agglomeration that is generated around this city. An investigation focused on the analysis of the intensification and the effects of the urbanization process of a rural and rururban area, from an integrative, transversal, and multiscale approach, supported by inductive and hybrid methodology, with quantitative and qualitative methods. Through this study, the evolution and problems of these spaces will be known, to analyze the processes that have occurred and continue to occur and, thus, propose measures to reduce the negative effects. The main results and conclusions of the research are manifested in transformations on a legacy space, which has been productively redefined, being one of the most changed since the middle of the last century.

Keywords: rural–urban interaction; deagrarianisation; economic tertiarization; urban expansion; land use

Citation: Lagüera Díaz, S. Urban Rural Interaction: Processes and Changes in the *Marina Oriental* of Cantabria (Spain). *Land* **2023**, *12*, 166. https://doi.org/10.3390/land12010166

Academic Editors: Xuesong Kong and María L. Gómez-Moreno

Received: 21 October 2022
Revised: 21 December 2022
Accepted: 27 December 2022
Published: 4 January 2023

1. Introduction

The urbanization processes that developed in Spain have been manifesting themselves more intensively on the territory since the nineteenth century and especially during the second half of the twentieth century, with characteristics that have been very similar to those of other countries, although at a different scale and pace.

These changes and transformations of urbanization, therefore, have not been an isolated case, but have been widespread, in most developed countries, especially in the last fifty years. A clear example is found in the United States, with a strong suburbanization after World War II. In Europe, cities have been more compact than in the American case, but their transformation also accelerated during the second half of the twentieth century, with a suburban trend, the rise of communication and transport networks, with very important environmental, social, and economic consequences, often irreversible [1].

Another clear example at the European level is found in Italy, where in recent years there has been a process of strong anthropic pressure that has generated the change of 90% of the coastal environment, leaving intact only 10% of the original habitat, where 30% of Italians also live [2].

This whole process has also been interesting in other countries outside the European Union, such as the case of China [3], where the urbanization process was promoted from the nineties onwards, with a great restructuring and interaction between rural and urban areas, with new rural economies and tourism, reflecting the change in land use, life and, ultimately, the economy [4].

In the Spanish case, this rapid and abrupt growth of urbanization processes has a great impact on highly vulnerable spaces, such as coastal rural areas [5,6], which makes it necessary to develop in-depth and extensive studies that reflect on it in an extensive way, in a context and a moment, in addition, of great importance and social involvement in environmental and sustainability issues. These spaces are the most suitable and attractive for construction, with a high growth rate and a boom in tourism and the artificialization of the territory [7].

It has more importance, if possible, within the *Marina Oriental*, a territory that has undergone enormous transformations both socially, economically, and urbanistically in a relatively short period of time, with a practical shortage of adequate planning and planning figures and updated to the requirements of each moment. In the processes of urbanization many factors such as social, demographic, economic and territorial, are involved. All of them come very close to the factors, closer and developed over time, that have a lot to do with the increase and improvement in mobility in recent years.

Thanks to the improvement of accessibility, transport infrastructures, access to the car, and, in general, the improvement of the standard of living, work movements have increased both in number and in travel distances. Thus, the population is no longer looking for such proximity to workplaces but is increasingly opting for places of residence relatively far from urban agglomerations, which are mainly those with the largest job market.

With this increase in mobility, it is possible to cover wider spaces thanks to the existing good connection, creating new residential environments outside urban agglomerations, in spaces previously dedicated to other uses and with other functions. These spaces, in addition, have become highly attractive for the population looking for a life outside the city but at the same time a good connection with it, due to their dependence for different reasons. Therefore, it has connected and brought the urban environment to the rural environment in a very remarkable way, restructuring many of its land uses and other characteristic features and generating an expansion of residential functions, in this case, especially, of a vacation and secondary nature, such as second homes, with a clear prominence of the area of the *Marina Oriental* of Cantabria.

If we analyze the evolution of cities, starting from the twentieth century, periods of stagnation and urban growth can be distinguished, which happened over time with different intensity. However, practically all of them have had a strong growth trend since the nineties until the period prior to the economic crisis of the early XXI century, when they went into an economic decline, generating a strong slowdown of the urbanization process that had been achieved [8,9] and that had marked the change in image of many Spanish territories.

It is during this period that Spanish cities underwent the most significant changes in terms of their structure and morphology through a dynamic in which new spaces and metropolitan areas are consolidated based on a diffuse urbanization model, making the task of differentiation and the boundary between urban and rural increasingly complex [10,11]. In relation to this process, there is talk of a new concept of urbanization, whose fundamental pillar is related to the dispersion of the central city, which some authors describe as "neourbanism", "new urbanism", emerged around the XXI century society, to differentiate it from the urbanism that emerged in previous eras. To this end, ten principles of what this new urbanism would be are established, oriented to respond to current urban needs. This process is characterized by the change in cities, which have been modernizing, adapting to new needs, and emerging new processes, such as "metapolization" [12], a new term that encompasses metropolization and the consequent formation of spaces that function independently, exceeding the limits of cities and occupying more and more rural spaces around them.

The first to realize that these processes were taking place were the American scientists, in the decade of the seventies, specifically in the field of demography, appreciating that there was an important movement of people who moved from the countryside to the city and vice versa, a movement that emerged especially around the search for work and better living conditions. In fact, they described a city–country migratory movement and pattern, partially contrary to that given in previous decades, which they called "counterurbanization" [13], with migratory flows in the opposite direction to those of previous ur-banization [14–16].

Little by little, due to the importance and transcendence that they were having in other countries, these dynamics were attracting the attention of many other experts. In this way, in recent decades they have spread to various territories, being the object of study in many countries and areas even on a smaller scale.

It is also necessary to consider the importance of the urban process on the environment and animals. The expansion of human settlement has also affected these media, conditioning their distribution, density, movement, etc., since changes in soil conditions are important for both landscapes and living beings. For this, an important tool, especially to visualize all these changes, is geovisualization, a tool that combines the tradition of cartography and geography but integrates the representation and analysis of data, which are useful for many everyday uses.

It is also important, in this introduction, to delimit the area of study that will be worked on and has already been cited previously, the *Marina Oriental* of the Autonomous Community of Cantabria, which, on a small scale, is a paradigmatic example of this process. The various municipalities that make up this territory have experienced remarkable growth dynamics because of the decentralization and dispersion of the great city of Bilbao, located in the Basque Autonomous Community, and, to a lesser extent, of the regional capital, Santander. A process, therefore, that has occurred above the political–administrative limits, which do not seem to have affected the functional configuration of this space, but at the internal level of the administrations, both local and autonomous, specifically in the matter of urbanism and endowments [17].

Therefore, the central objective of this research is to demonstrate the importance of this space, undoubtedly, a large part of which is functionally integrated into the metropolitan area of Bilbao, with numerous changes in its social, economic, urban, and ultimately territorial and landscape structure, in a short and intense time. Therefore, the process of expansion in the urban areas of Bilbao and Santander should be considered the engine of the changes experienced in the Marina Oriental.

To do this, we will start from the central hypothesis, which will be discussed and verified throughout the document, based on the fact that, since the middle of the last century, Cantabria, and especially the *Marina Oriental*, has been intensely affected by urbanization processes, more specifically of perimetropolization, starting from the growth and urban dispersion of Bilbao mainly and of the regional capital, Santander, secondly, giving rise to a series of important territorial changes and impacts, especially de-urbanization and tourist tertiary, as well as population and real estate growth, which entails a partial territorial disarticulation.

It is important to frame the research and its importance when answering a series of questions that arise here. As mentioned in the hypothesis, an urbanization process that has taken place very intensively on a territory that has undergone major transformations in a very short time will be analyzed. This process brings with it a series of problems and deficits, which in many cases are practically impossible to solve, so this research aims to answer all this.

Recent economic, demographic, or social changes, among others, have profoundly modified rural and urban areas, thereby generating the appearance of new types of territories characterized by different degrees of urbanization. Hence the large number of techniques and typologies of the classification and cataloguing of these spaces that exist and that have emerged especially in more recent times [18].

Defining and differentiating rural and urban spaces has become a complex task. The concept of rural has been changing during the last decades from being a synonym of backwardness and only linked to agrarian activity to having more and more positive meanings and being associated with quality of life, with much more variety of uses, economic activities, and functions than it had in the past [19,20]. It has gone from rural spaces whose only function was essentially the production of food and raw materials to something more plural and multifunctional, defined by many authors with the expression "new rurality"[1]. This concept is being widely used in recent times to describe the novel forms of organization and change of functions in non-urban spaces.

What we see today in most rural areas is a progressive de-dollarization and tertiarization of the economy, where agriculture is progressively losing weight in favor of other activities; in fact, it currently occupies just over 4% of the total assets in Spain, according to the latest active population survey, consolidating with it a rural pluriactivity. For its part, outsourcing has been gaining weight, and today it occupy to a very high percentages of assets; specifically, according to the latest data referred to in the previous source, it covers about 70% of the economy. On the other hand, the rest of the sectors, such as industry and construction, dealing 12% and 6% of the assets, respectively.

Another remarkable fact is the so-called "urban exodus" or counterurbanization, a process by which some types of rural spaces have been recovering the population that little by little they were losing during the main period of the "rural exodus" started in the sixties and that has continued for several decades.

2. Study Area

The *Marina Oriental* is located between the southern area of the Santander Bay arch and the border with the province of Vizcaya. It is 60 km long and 477.12 square kilometers, that is, almost 9% of the total area of the Autonomous Community of Cantabria. Despite its limited dimensions, it is one of the most developed areas and has the greatest population and economic weight within the region.

The study area consists of a total of seventeen municipalities, from east to west: Castro Urdiales, Liendo, Guriezo, Laredo, Colindres, Limpias, Bárcena de Cicero, Santoña, Argoños, Escalante, Noja, Arnuero, Meruelo, Bareyo, Ribamontán al Mar, Marina de Cudeyo, and Medio Cudeyo (Figure 1).

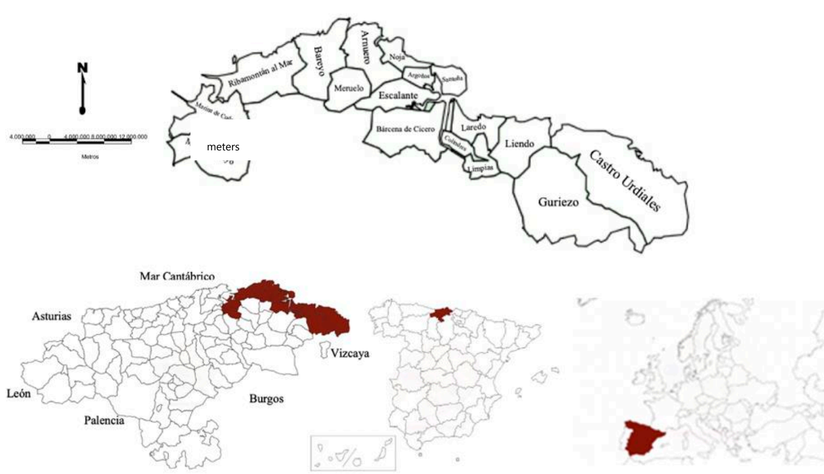


Figure 1. Study area of the *Marina Oriental* of Cantabria. Source: own elaboration based on the cartography of the National Geographic Institute (IGN) and the Government of Cantabria.

Several common attributes that define and differentiate this space from the *Marina Oriental*. The first of these is the characteristic relief, which in turn will define the coastal landscape of the environment. The set of these municipalities is not long than ten kilometers from the coastline, influenced by the dynamics and coastal ecosystems. The sea is therefore a key and valuable natural element that has directly influenced the human being and with it the territories on which it inhabits, both positively and negatively.

In fact, this area can be considered the part of Cantabria, along with the rest of the coast of the region, more anthropized and pressured by human action. However, it is at the same time a territory with a high landscape and environmental value that, on occasions, has been kept practically intact until relatively recently.

This territorial area also stands out due to the great tourist reception it produces every year and that is especially concentrated during the central summer months and festive periods. The reasons for this attraction are mainly the tourist and landscape resources it has, focused especially on the numerous beaches and the attractive landscape, one of the references and elements of greater value of the study area. In addition, it has a wide range of both hotel and non-hotel accommodation and secondary housing [21,22].

To this is added a dense and complete communication network and road network (Figure 2) governed by the axis of the Cantabrian Highway A-8, which allows fast and effective communication with the Basque and Asturian Autonomous Communities, as well as with the plateau highway A-67, which connects inland with the Autonomous Community of Castilla y León.

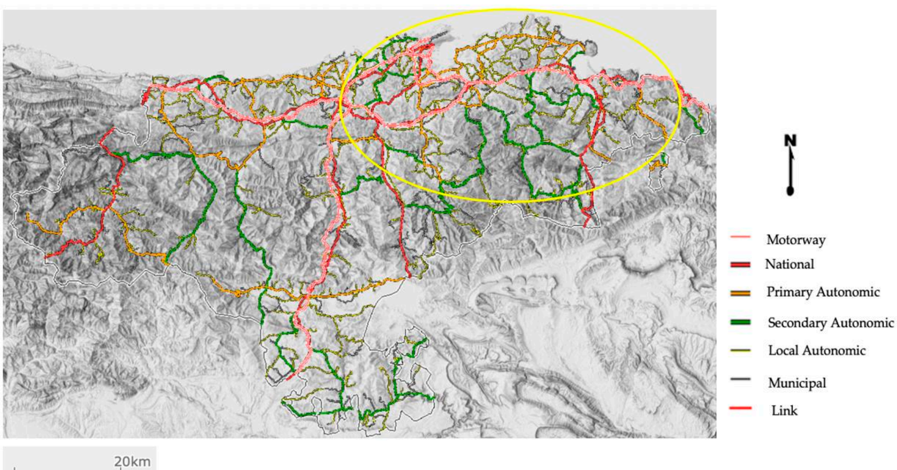


Figure 2. Network of Cantabria on relief map. Source: Ministry of Public Works, Spatial Planning and Urban Planning of the Government of Cantabria. Digital model of the terrain.

3. Materials and Methods

The methodology applied in this research is of an inductive and hybrid nature, with quantitative and qualitative methods, based on the study of a series of indicators that have allowed the verification of the urbanization processes that have occurred in the space of the *Marina Oriental* of Cantabria, all with the completion of the essential fieldwork. This fieldwork has been carried out visiting all the municipalities of the study area, analyzing the current social, economic, and urban situation, to understand the changes that have developed over time. Photos have been taken, aerial images through drone; data have been obtained from different municipal agencies, the locals, etc.; in short, an attempt has been made to exploit each territory as much as possible.

Quantitative indicators have also been used to measure urbanization processes in other territories and scales. Its application is essentially at the local level. These indicators are mainly of a socio-demographic, economic, urban, and real estate type, addressed within a time ranging from the middle of the last century to the most recent data of each analysis variable.

These statistical data will be obtained mainly from sources generated by the National Institute of Statistics (INE) through its censuses and annual registers. Data such as the summer population figure or daily movements have been obtained in most cases through estimates. However, they are tools that, although their information is not error-free, are the most reliable and with the data available to the study territory.

Regarding socio-demographic indicators, the evolution of the population has been analyzed through the censuses and registers carried out every decade and every year, respectively. The natural population movement, by sex and age groups, will also be considered to know the results in more detail. Likewise, they have been established according to their economic activity, which will link up very well with economic indicators, and thus know the active population by sectors of activity. Another indicator has focused on the linked population, that is, who is not registered but who makes use of the municipal territory for a certain reason. The migrations and migratory patterns of the population are also of interest.

In terms of economic aspects, the change in activity that has taken place in the municipalities of the study area has been analyzed, where the deagrarianization and tertiary economic have been the predominant processes. Attention has been focused on the analysis of the active population by sectors over the years and the evolution followed by each of the sectors.

The urban and real estate evolution in terms of homes and buildings has also been studied, considering various indicators such as the number of homes and buildings built over the years, their age, typology, heights, etc. essential data to know the urbanization processes and detect the change of use of homes. In this case, we have again resorted to the data from the housing statistics provided by the National Institute of Statistics. In addition, the housing and land use data of the Ministry of Public Works have been used, based on the results of the *Corinne Land Cover* projects and the Information System on Land Occupation in Spain and the Cadastre data, accessible electronically.

In addition, images, cartography, and photographs are fundamental instruments in a more qualitative study, since through them it has been possible to compare the past situation with the current one, analyzing the changes and transformations that have taken place, as is the fieldwork to support all the above.

As for the study period, it has been adjusted to the one comprised of the fifties of the last century to the present, since it is broad enough in time to appreciate the most significant changes, but in greater detail in the nearest decades, from 1980 and 1990 onwards. Therefore, a period of more than fifty years will make evident the transformation that has been occurring.

4. Consequences of the Urbanization Process

4.1. Recent Demographic Dynamics in the Marina Oriental

The current 584,407 inhabitants of Cantabria are very unevenly distributed throughout the territory, with a settlement model that is not balanced. Specifically, our study area currently hosts more than 100,000 inhabitants on a regular resident basis, a figure that rises well above if we consider the population linked to them, as will be discussed later.

As for the population evolution, the set of the seventeen area municipalities of the *Marina Oriental* experienced an important and constant growth until the first decade of the current century. From that moment on, the growth maintained, constant and stable (Figure 3) until we get to the present, which explains the population fixation on this space, slowing down the great growth that until now was taking place.

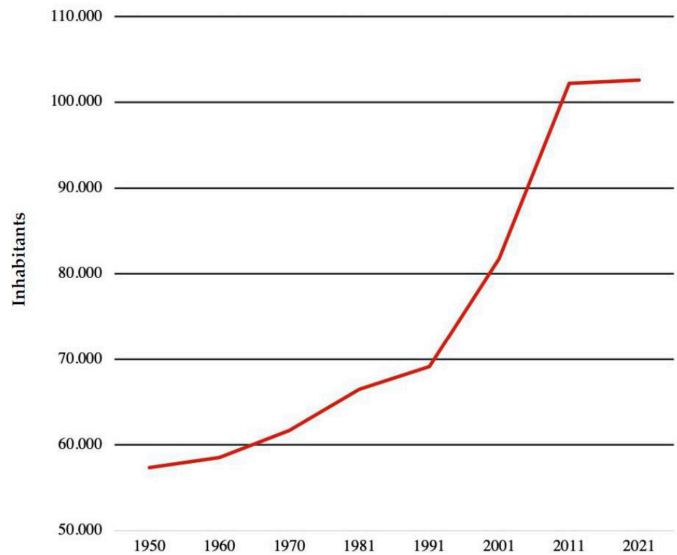


Figure 3. of the *Marina Oriental* between 1950 and 2021 (absolute values). Source: own elaboration based on the data of the Population and Housing Census. Series Stories of Population. National Institute of Statistics (INE).

This population variable has great importance within the territory, especially in the municipalities closest to the metropolitan area of Bilbao, such as Castro Urdiales (32,270 inhabitants), Laredo (11,023), and Santoña (11,019), the three cities with the largest population entity within the study area. There are a small number of municipalities, in this case five, Limpias (1974 inhabitants), Bareyo (1950), Argoños (1748), Liendo (1204), and Escalante (762), rural from a strictly quantitative and statistical approach due to their amount of population, which contrasts functionally with the rural municipalities of the interior of Cantabria with a similar demographic volume (Figure 4).

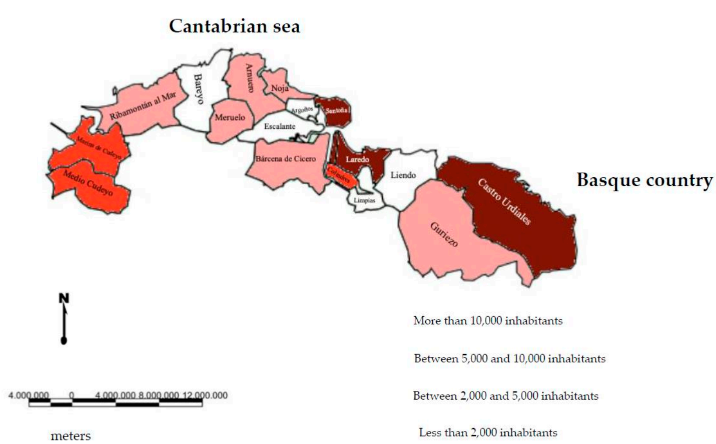


Figure 4. Population volume in the *Marina Oriental* de Cantabria, year 2020. Source: own elaboration based on the data and the categories established by the National Institute of Statistics.

It is an area with a great population dynamic, which has experienced, like other important nuclei of the region, high population growth, especially since the nineties of the twentieth century. A notable example is Castro Urdiales, which maintained stable growth until the nineties, with figures less than 13,000 inhabitants, comparable to Laredo, and, from that moment on experienced a great increase, with highs in 2011 around 32,000 registered inhabitants. However, this city has a real population figure of more than double, counting the population that permanently resides here but has not officially registered its registration, according to the data provided by municipal bodies, such as water and garbage consumption data, which offer an estimate of the real population that the municipality hosts.

The population evolution, of course, has not been followed in the same way by all the municipalities that make up the *Marina Oriental*, since each one has had its internal trend, although they were in general, similar, especially until the end of the twentieth century (Figure 5).

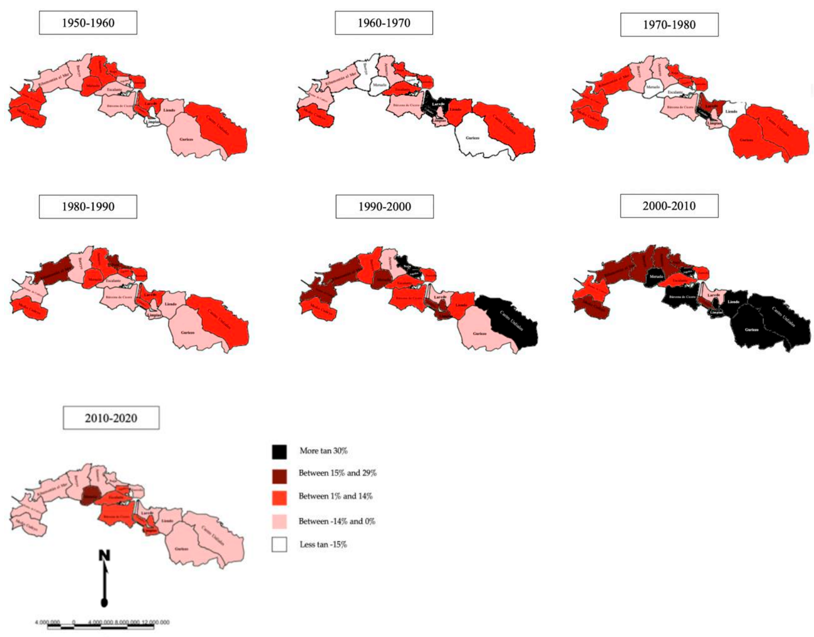


Figure 5. Percentage population evolution of the municipalities of the *Marina Oriental* by decades. Source: own elaboration based on the data of the Population and Housing Census. Historical Population Series. National Institute of Statistics (INE).

There are cases, however, in which there are small demographic losses in some of its nuclei, especially in the most urban ones, with population decreases of 1611 inhabitants (−13%) in Laredo and 537 (−5%) in Santoña during the last decade. In these cases, it is not a symptom of decline linked to rurality but of the peri-urban redistribution that has also begun to occur in the small towns of the *Marina Oriental*.

As has already been pointed out before, this area has also been partly nourished by a population of Basque origin, with high population figures, especially during certain times of the year, but it is a floating rather than resident population.

It is essential, therefore, to focus attention on the importance of the linked population[2] in the study area of the *Marina Oriental* of Cantabria, especially because they reside in their second homes for many parts of the year. This circumstance has been evident since the seventies of the twentieth century, but it has intensified since the last decades of the last century, when the second home of a holiday nature had great importance, especially in coastal areas.

Thanks to the improvement of accessibility, transport infrastructures, access to the car, and, in general, the improvement of the standard of living, work movements have increased both in number and in travel distances. So the population is no longer looking for proximity to workplaces but is increasingly opting for places of residence relatively far from urban agglomerations, which are mainly those with the largest job market.

The mobility has increased enormously in Bilbao and its metropolitan area, as well as in the easternmost area of Cantabria, especially Castro Urdiales, place chosen by many Basque popula-tion for their place of residence. Their work destination continues to be mostly the metropolitan area of Bilbao, but they decide to move daily from one place to another, due to its proximity. All this generates great mobility, which is practically impossible to evaluate and account for because this population has not changed the registration of registration [23] and they continue to be registered as Basque inhabitants, even if they live in Cantabria

In addition, the impact of the COVID-19 pandemic that has affected the entire country has altered mobility enormously. Mobility restrictions have been strict and repeated throughout 2020 and 2021, causing major disruptions in people's daily lives and mobility.

In fact, mobility between Cantabria and the Basque Country has increased after the confinement phases established by the State of National Alarm, since, after the opening of the perimeter closures, there was a lot of the Basque population that went to their Cantabrian places of second residence within very specific days, which were those allowed, therefore increasing mobility but also traffic congestion. It is important to point out the duration of this state of alarm, in force in Spain since March 2020, with the impossibility of daily commutes until the central months of that same year.

To corroborate all the above, since the end of 2019, the National Institute of Statistics has considered conducting a mobility study with data obtained through mobile phones. With the outbreak of COVID-19, this study became much more interesting, to know the mobility of people during the declared State of Alarm, obtaining a series of results of notable interest in the eleven areas of mobility within the area of the *Marina Oriental* of Cantabria.

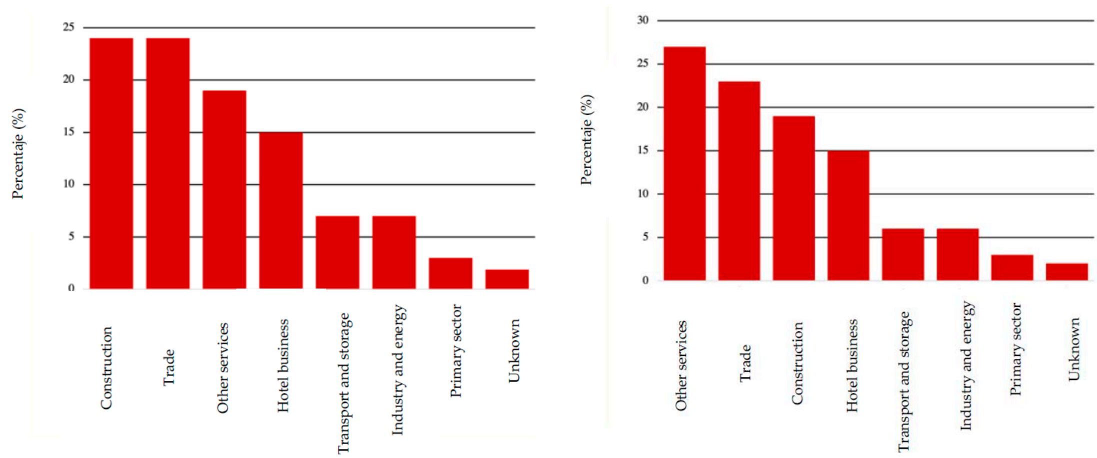
In all areas, the mobility of people who leave the study area increased during the central months of 2020, when mobility was allowed, declining again at the beginning of 2021 and increasing again during the central summer months, when mobility was practically the same as before the pandemic. In terms of volume, the largest percentage of the population that leaves their area of residence daily corresponds to the municipalities of Marina de Cudeyo (35% of its population), Bárcena de Cicero, and Escalante (25%), as well as Colindres (22%); departures are mainly destined for both the metropolitan areas of Santander and Bilbao, especially for work.

4.2. Changes in Economic Structure and Dynamics

The most important economic sector in the region today, as has been said, is that of services, with 75.1% of assets in the region in 2020, followed by industrial activity with 14.5%, construction with 7.3%, and, finally, agriculture with 3.1%.

The changes in economic activities that have occurred today have generated the transition from an economy based on the activities of the primary sector, livestock, and fishing, to an economy practically focused on the tertiary sector, on services, especially those linked to tourism.

As for the business structure of the activity between 2009 and 2019, most of the establishments are focused on repair (more than 2500 establish-ments), construction (more than 2000), and hospitality (almost 1500). With the compa-nies, we see a significant percentage of them in 2009 corresponding to construction and trade, both close to 25% of the total companies of the Marina Oriental, followed by the rest in services, with almost 20%. In 2019, the situation varied a little, since the largest percentage correspond to the rest of the services, exceeding 25%, with trade and construction decreasing in importance, the latter below 20% (Figure 6 and Table 1).



(A) 2009 **(B) 2019**

Figure 6. Business structure in 2009 and 2019 in the *Marina Oriental* of Cantabria. Source: own elaboration based on the data of the Directory of Companies and Establishments of Cantabria. Cantabrian Institute of Statistics (ICANE).

Table 1. Percentage of companies by industrial activity in the municipalities of the *Marina Oriental* de Cantabria in 2009 and 2019.

	2009				2019			
	Agriculture and Fisheries	**Industry**	**Construction**	**Service**	**Agriculture and Fisheries**	**Industry**	**Construction**	**Service**
Argoños	4	2	2	1	6	3	2	1
Arnuero	3	1	4	2	4	1	4	3
Bárcena de Cicero	4	5	4	3	7	6	5	3
Bareyo	5	0	4	2	12	1	3	2
Castro-Urdiales	17	19	21	27	8	17	24	27
Colindres	7	7	10	7	3	6	9	7
Escalante	1	1	0	1	2	1	1	1
Guriezo	1	2	2	2	4	2	2	1
Laredo	10	9	16	16	6	13	15	15
Liendo	1	1	3	1	2	0	2	1
Limpias	0	2	2	1	1	1	1	1
Marina de Cudeyo	11	10	3	4	11	11	4	5
Medio Cudeyo	10	14	6	9	9	15	7	9
Meruelo	3	3	3	2	4	3	3	2
Noja	2	1	8	5	1	1	7	6
Ribamontán al Mar	13	4	5	5	15	3	5	5
Santoña	9	17	7	12	7	17	7	12
MARINA ORIENTAL	**25**	**17**	**19**	**17**	**20**	**17**	**17**	**16**

In the study area, as for the whole of the Cantabrian region, the agricultural sector, especially livestock activities, has been of vital importance for the economy. Likewise, fishing is a traditional activity that has been gaining more and more importance weight ver time. The construction of fish canneries has been the fundamental factor in the transformation of the sector, thereby changing the entire fishing system, the production process, techniques, etc., going from a practically subsistence system for the population to being a consolidated and productive economic activity [24,25].

All these changes in the current trend can be understood, in general terms, as a "rural restructuring" [26], referring to a change in the productive structure of rural spaces since the beginning of the seventies, when the processes of deagrarianization in Spain ere beginning to be noticed and, although to a lesser extent in recent times, by increasing mobility between the city and the countryside.

This is evident in the study area through a series of indicators, such as the decrease in the number of agricultural holdings, especially since the nineties, with reductions exceeding 90% between the end of the seventies and the present. If in 1972, we found more than 6000 farms in the study area, what we see today is the presence of just over 1000 farms, that is, a reduction of more than 80% in less than forty years of study, in each one of the municipalities, without exception, especially pronounced since the nineties.

Therefore, there was a loss of importance in terms of the number of livestock farms, which became almost complete in some municipalities, such as for example in Santoña, where there are only twelve agricultural farms left, representing less than 1% of the total farms of the *Marina Oriental*, or Noja or Colindres, with twelve and thirteen farms respectively, also representing 1%.

Another result of the loss in activity comes hand in hand in the variation of the size of the farms is that there has also been a change in the trend, with farms preferably of small size (less than 20 hectares), which constitute 80% of the total farms in the study area. These farms, despite being the most predominant, have also seen the number of medium and even large-sized farms (more than 50 hectares).

Everything mentioned above also translates into a reduction in the useful agricultural area occupied by these farms, which, of course, has been reduced. The useful agricultural area has gone from exceeding 42,000 hectares for the whole of the *Marina Oriental* in 1972 to standing at just over 14,000 by the year 2020 (Figure 7). If it is analyzed at the municipal level, it can be seen how the reduction has been very intense between 1972 and 2020, with municipalities that have practically completely lost their agricultural use area, such as Santoña, Liendo, Guriezo, Noja or Castro Urdiales, with reductions of around 98%.

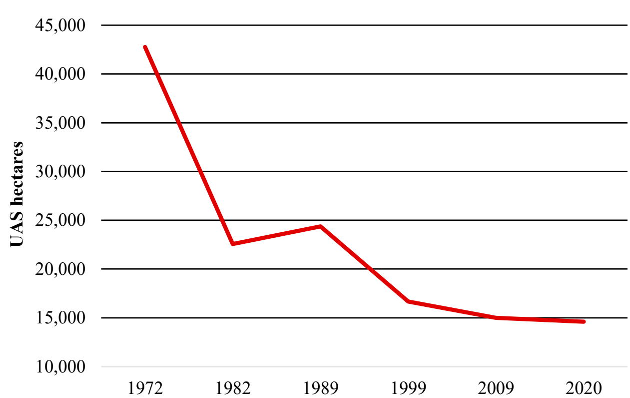


Figure 7. Evolution of UAS hectares in the *Marina Oriental*. Source: own elaboration from the agrarian censuses.

In addition, there has been a change in the tenure regime of these farms, in parallel with this process of privatization. Over the years, there has been a change in land ownership towards leasing. As for the age of the holders of the holdings, it is seen that there have also been variations. At the beginning of the seventies in the study area, the highest percentage of owners were of ages between 35 and 54 years; however, at present the trend has turned towards older owners, in this case between 55 and 64 years, which supports that another feature of deagrarianization is the disinterest of young people to continue with agricultural activity [27].

Despite this, the number of cattle has been increasing over the years, from 37,500 in 1982 to 269,640 in 2019, especially highlighting the cattle, the most important within the area of the Marina Oriental, the half of the total and even in some municipalities reaching higher percentages, such as Ribamontán al Mar (73%).

However, dairy quotas have been reduced. These began to be applied after Spain's entry into the European Union, trying to balance supply and demand in terms of dairy production and eliminating production surpluses. There were maximum quotas between 2002 and 2005, above 103,000,000 kilos of milk, to be reduced from there until it stopped being counted in 2015, when was around 96,000,000 kilos, with differences, logically, at the municipal level. Since that moment, milk production data were taken from industry, where the municipalities with the highest contribution are Ribamontán al Mar (26% of the quotas), Marina de Cudeyo (18%), Bareyo (15%), and Arnuero (11%), that is, those with the highest maintenance of the activity.

If the employment structure is taken as a reference, it can be seen how the primary sector has decreased for the entire study area, from 1999 to 2019, with a progressive decrease in its percentage of assets. All this presents nuances, since, despite the generalization in the loss of activity, there have been municipalities that have known how to safeguard the activity, despite not being the one with the greatest weight at present, employing a significant volume of population.

Internal differences can be seen within the study area. On the one hand, municipalities that from 1999 to 2019 have greatly decreased the number of employees in the sector, such as Argoños (from 6% to 4%), Colindres (from 14% to 6%), Guriezo (from 7% to 1%), Laredo (from 11% to 3%), or Santoña (from 16% to 6%), taking into account that in Colindres, Laredo, and Santoña, many of the employees in the primary sector are not agricultural but fishing. On the other hand, the westernmost municipalities increased the numbers of agricultural employees between these dates, such as Arnuero (from 0% to 3%), Bárcena de Cicero (from 2% to 4%), Escalante (from 2% to 4%), or Ribamontán al Mar (from 0% to 5%).

The highest value corresponds to the municipality of Bareyo, which has the highest percentage of agricultural active population with 6.7% (Figure 8). On the contrary, other municipalities present percentage figures in some worrying cases of the abandonment of the activity, as for example in Noja, with percentages of agricultural population of 0.2%, Castro Urdiales with 0.3%, or Limpias with 0.6%, insignificant percentages for an activity that has been the economic pillar for this region in not-so-distant times. Faced with this fact, little by little, alternatives are being created to generate work and activity in rural and peri-urban spaces, so that they do not completely lose the essence and rural identity that has characterized them for many centuries (Figure 6).

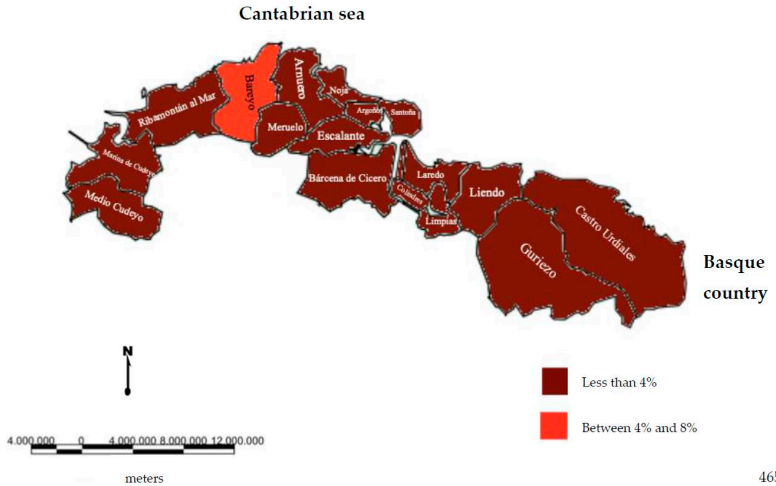


Figure 8. Percentage of agrarian population in 2020 in the municipalities of the *Marina Oriental* de Cantabria. Source: own elaboration based on the exploitation of microdata of the active population surveys. National Institute of Statistics.

4.3. Tourism Tertiarization

Deagrarianization and the loss of agricultural activity are being counteracted with a boom and importance of tertiary and service activities, that is, with a socio-economic outsourcing, especially focused on tourist and hotel accommodations. The territory of the *Marina Oriental* hosts 40% of the total hotel places that Cantabria has and almost 12% of the places for rural tourism houses. Of this 40% of hotel places, two municipalities stand out with more than 20% of places, Arnuero with 20.6% and Noja with 25.6%. They are areas with many places due to the development of hotel accommodations that have been built in both municipalities and that offer tourists an alternative of accommodations outside of residential tourism that prevails in the rest of the territory.

Another of the most successful accommodation models within the territory of the *Marina Oriental*, where there is a large number, the campsites. This accommodation model is a relatively recent tourist variety in Spain, since it has been developed over the last decades, especially in the areas closest to the coast, becoming a fully consolidated model. Specifically, within the territory of the *Marina Oriental*, we find 23 campsites, that is, 46% of the total.

This service sector, which already had the highest percentages of assets at the end of the nineties (about 60% in 1999), saw a slight reduction for the year 2009, increasing later in the year 2019, occupying practically 80% of the assets of the *Marina Oriental* of Cantabria. The almost total percentage focuses on the demand around the services sector, with percentages above 60% in all cases.

In addition, it is appreciated that the unemployment figures are focused especially around the sector with the largest number of employees, the services sector, higher than 80% on certain occasions, as in the case of Argoños (81%), Bareyo (82%), Meruelo (83%), Noja (86%), or Ribamontán al Mar (81%), which generates a great problem linked to the loss in the diversity of economic activities and also high unemployment figures. To this is added its seasonality, since it is practically developed at certain times and periods a year, and the rest of the time, many of them, especially in the most touristic municipalities of the *Marina Oriental*, struggle to maintain themselves and be viable.

Regarding the structure of establishments and companies, the service sector constitutes the almost complete predominance of the study area, which reached very high percentages in 2009, such as in Laredo, Medio Cudeyo, or Santoña, where establishments of this type exceeded 70%. It also highlights the percentage of establishments dedicated to construction, at a time when the crisis in the sector had begun, but the companies related to it were still very numerous. In 2019, the situation remains similar and services again have the highest percentages of importance in terms of establishments, all of them with percentages higher than the 48%.

As for the industrial sector, it has experienced a generalized decline during the years of study within the area of the *Marina Oriental*. Among them, the area of the mouth of the Asón stands out, such as the installation of SEG Automotive Spain in Bárcena de Cicero, as well as various industrial estates such as in Medio Cudeyo or Castro Urdiales. Despite this, the predominance in terms of industry is formed by small facilities. While assets increased from 1999 to 2009, especially in the municipality of Bárcena de Cicero (with more than 35% of employees) or Colindres (with almost 35%), they decreased in 2019 in general, with the lowest weight of employees in the sector being the municipality of Noja (with 4%) and the one with the most Santoña (with almost 20%). The percentage of assets in this sector increased until the impact of the financial crisis in 2009, and from then, until the present, it was reduced again.

In order of importance, industrial activity is followed by construction, which, although it has decreased since 2009, due to the crisis in the sector, still has a lot of weight within the area.

Construction, like the industry, saw its assets increase until 2009, again to be reduced today, below the values it had at the beginning of the analysis. The construction sector saw its figures increase in 2009 to later decrease in 2019, its highest in the municipality of Marina de Cudeyo (more than 15%), with the rest of the municipalities being around 5% employed.

For its part, the services sector, which already had the highest percentages of assets in 1999 (about 60%) had a slight reduction around 2009, increasing later in 2019, occupying practically 80% of the assets of the *Marina Oriental* of Cantabria, which endorses the importance of this sector within the study area, with almost absolute weight over the rest of the sectors. In addition to being the one with the greatest importance and weight in all the municipalities of the study area, it is the sector with the greatest increase for the analyzed period, with continuous promotions, in all the municipalities, with more than 65% of employees around the sector.

5. The Intensification of Urbanization Processes

As has already been reiterated, most of the changes that have been exposed have had their origin in the metropolitan growth of Bilbao (Figure 8) and in the construction of infrastructure that connected both spaces in a fast way since its construction, the Cantabrian Highway, A-8, which increase the strong urbanization process that occurred in this space in recent decades.

According to the study of the National Institute of Statistics (INE) on functional urban areas[3], Bilbao covers a large part of the territories that make up the *Marina Oriental* of Cantabria, as we will see below (Figure 9). The metropolitan area of Bilbao is an urban space that covers an area of more than 300 square kilometers, made up of about thirty municipalities in more than one million people live. Within this space, there is the presence of municipalities belonging to the *Marina Oriental*, such as Castro Urdiales and Guriezo, among others, which are today functionally integrated completely into the metropolitan area of Bilbao [18]. It is metropolitan growth that has exceeded administrative limits and has grown enormously, exceeding previous expectations and esti-mates.

Figure 9. Delimitation of the metropolitan area of Bilbao (Functional urban area). Source: National Institute of Statistics.

In its urbanization dynamics, the role of secondary housing or into this space, with values that reach such high figures in certain municipalities as to consider them "paradigmatic examples".

In the *Marina Oriental*, as happens in many other places on the Spanish coast, such as the Mediterranean, Levantine, and Andalusian case, the intensification of recent urbanization processes is linked to tourist activity, but they also have multiple elements linked to holiday residentialism. Many municipalities in this territory receive a large population, especially of Basque and Madrid origin, who have opted for the acquisition of homes for the enjoyment of leisure time in a coastal destination like this or as an investment [28,29].

As can be seen in the graph (Figure 10), the main growth in the housing stock in Cantabria and in the *Marina Oriental* has occurred during the last decades in proportions higher than the increase in the population.

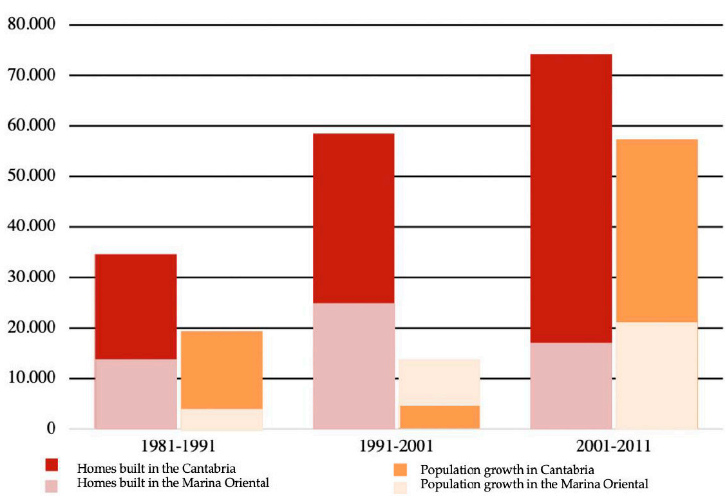


Figure 10. Evolution by decades of the total number of homes built and population growth in number of inhabitants for Cantabria and the *Marina Oriental.* Source: own elaboration based on the data of the National Institute of Statistics.

As can be seen, the number of homes built in the region since the eighties of the twentieth century has always been higher than population growth, with great differences between both variables, especially between 1991 and 2001, when the volume of homes built grew greatly and the population barely did. Housing growth continued in the decade between 2001 and 2011, reaching its peak for that period, with the construction of more than 70,000 homes.

In the *Marina Oriental*, the number of homes built was higher than the population growth between 1981 and 2001, reaching its maximum in the decade between 1991 and 2001, with a construction of more than 25,000 homes.

In the Marina Oriental is the development of young residential park, since most of the houses have been built since the ninenties, with an average, therefore, of about thirty years for the total age of the houses. It was during the nineties, when most homes were built (25%), followed in importance by the first decade of the two thousand, with more than 20% of homes. In fact, it highlights the existence of years in which the percentage of increase in new homes with respect to the total real estate stock has been higher around the *Marina Oriental* than in Cantabria, especially since the eighties (Figure 11).

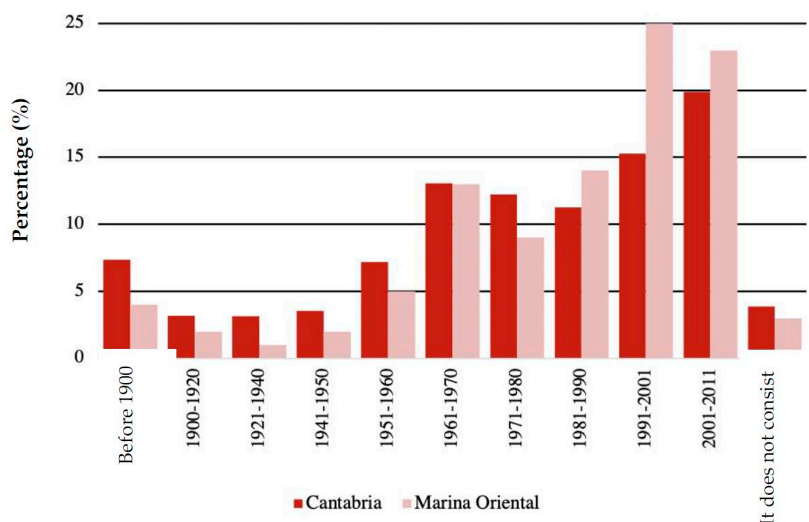
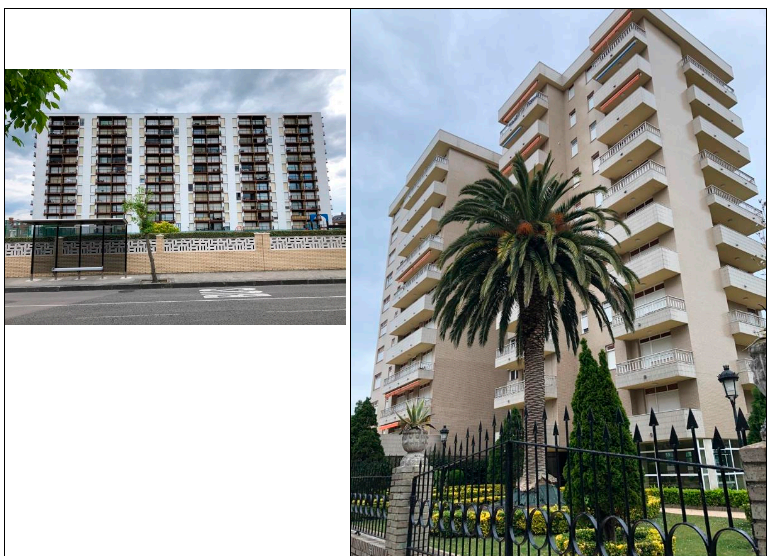


Figure 11. Comparison of the evolution by decades of the total number of homes built in Cantabria and the *Marina Oriental*. Source: own elaboration based on the data of the National Institute of Statistics (INE).

The great dynamism of residential construction that took place in the study area, especially since the nineties, resulting in the fact that practically all their residential park has been built since that moment, as in the case of Noja (Figure 11) or Castro Urdiales. For its part, Laredo is a previous tourist residential park, from the sixties and seventies, located around Salve Beach (Figures 12 and 13).

Figure 12. Residential construction in Noja. Source: own images.



(**a**) Block of flats on the beach of Laredo

(**b**) Block of flats on the beach of Laredo.

Figure 13. Residential construction around Salve Beach (Laredo). Source: own images.

The Multi-family type housing (50% of the total housing stock) it has a rural profile, since they have been established in municipalities that, in most cases, do not exceed 5000 inhabitants registered. Since the eighties this model has been consolidating to take advantage the most of the available buildable land. There is also a large presence of isolated housing, usually one or two floors, with such as enclosures for stables, garages, or storage areas.

This process has caused great transformations in the territory and the landscape of the Marina Oriental, especially on the rustic land, which has sometimes been converted into urbanizable and urban land, called "rururbanization"[4] processes [30], the initial mechanism of diffusion and dispersion of the city in the rural space [31].

This process has manifested itself in a very intense way in Marina Oriental gener-ated, above all, by the lower price of buildable land in relation to in the Basque Country, as well as by the unique socio-political circumstances of the Basque Country in previous decades. This entails some problems derived from the superiority of floating linked population that consumes services and equipment but does not contribute with its taxes to construction and maintenance.

At this point it is necessary to talk about the importance that second homes have acquired in the *Marina Oriental* of Cantabria. As mentioned before, the volume of secondary housing throughout Cantabria, but especially in the *Marina Oriental*, is highly substantial, exceeding on many occasions the number of main homes and constituting in some municipalities practically all the homes in its real estate, as in, for example, Laredo, where secondary homes represent between 60 and 80% of the total, or Noja, with 91% of secondary homes in 2011 (Figure 14).

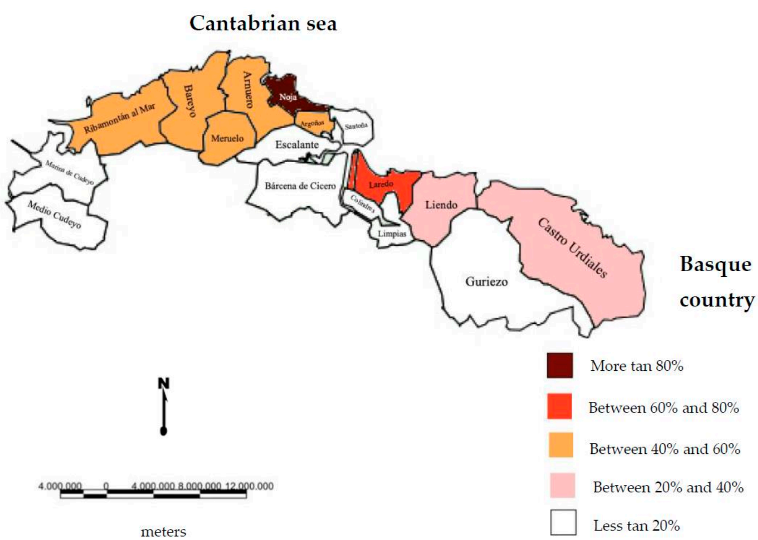


Figure 14. Percentage of secondary housing in the municipalities of the *Marina Oriental* for the year 2011. Source: own elaboration based on the population and housing censuses. National Institute of Statistics (INE).

In fact, the municipality of Noja occupies number one in the ranking of the entire Spanish territory as the municipality with the highest percentage of secondary housing in relation to the volume of the housing stock, above highly touristic municipalities such as Salou in Tarragona, Benicasim in Castellón, Mojácar in Almería, or Punta Umbria in Huelva, among others, for the year 2011.

As for the use given to these secondary homes in the *Marina Oriental*, it is characterized by being seasonal. They are occupied during the summer period, at other holiday times and even on weekends, although there are exceptions, such as Castro Urdiales where many of the homes registered as secondary are, in fact, permanent homes of the non-registered population.

In residential construction stress the multifamily block housing with between three and five floor, except in Laredo, which is sometimes described as the "Benidorm of the north", where ten levels are frequently exceeded. With this typology, the builders were able to make more intensive use of the soil than with the construction of isolated single-family houses, which consume a large amount of land.

The little controlled form of urbanism that has taken place in the *Marina Oriental* has had great effects on the landscape, creating totally artificial scenarios, the result of real estate speculation, whose objective is the maximum use of the land and not the sustainable management of it, hence the predominance of the most intensive architectural typologies. It has not been uncommon for this urbanization process to sometimes produce irregularities that have led to the demolition of homes classified as illegal, as well as the presence of many works stopped. All this has occurred despite the validity of several legal norms of urban and territorial planning in the Coastal Management Plan (POL), which was approved in 2004 and which can be described, without fear of equivocation, as the most important instrument in terms of management and planning in the *Marina Oriental*. The fundamental problem derives from the fact that the intense and accelerated process of urban expansion has developed in poorly adequate conditions, especially using the normative figures of territorial planning at the municipal level, some of them obsolete or poorly adapted to the great urbanizing pressure: only 47% of the municipalities of the *Marina Oriental* have a General Urban Planning Plan (PGOU), while 53% only have Subsidiary Planning Rules (NNSS).

The articulation of the territory in the study area of the *Marina Oriental* follows certain patterns and trends that it is necessary to analyze the concept of "territoriality", a complex and important concept, which allows greater flexibility when cataloguing various territories in relation to different criteria. Thus, within the study area, considering this territoriality and the characteristics that, on the ground and in fieldwork, are verified; the territory of the *Marina Oriental* will be articulated in three large groups or zones (Figure 15).

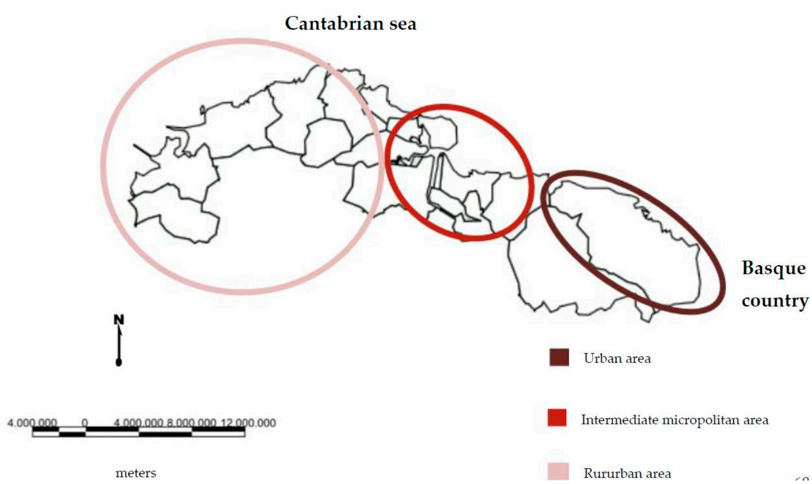


Figure 15. Areas/sectors of the *Marina Oriental* based on its territorial articulation. Source: own elaboration based on the cartography of the government of Cantabria.

On the one hand, the evidently more urban area is to the east, with the urban nucleus of Castro Urdiales; on the other hand, the conurbation formed in the intermediate part by the nuclei of Santoña, Laredo, and Colindres, and the area further west, eminently more rural, made up of the territory of the old historical region of Trasmiera.

6. Discussion

The discussion leads us, in short, to see how the hypothesis that has been proposed is verified and at the same time has coherence with the bibliographic framework.

Firstly, according to the methodological framework, the objective was the geographical analysis of a coastal territory of Cantabria, articulated by seventeen municipalities of diverse nature and typology but which act as a common space, well integrated and differentiated from the rest of the Cantabrian territory, positioning itself as the focus of greater development in recent decades within the region, with great attraction, especially in the metropolitan area of Bilbao and to a lesser extent in the metropolitan area of Santander.

The sea has played an important role here, hence the designation as *Marina*, a term in recent use, understood as that territory that has proximity to the sea.

All this will have a direct and important impact on the population, a variable of great importance in the development of this study, the result of the intensification of urbanization processes in this space, being the area of greatest growth and population dynamics in recent decades. In this way and recently, especially since the middle of the last century but more intensely since the nineties, this space of the *Marina Oriental* of Cantabria has experienced great population growth in each one of the seventeen municipalities of study.

There has been remarkable population growth in the study area, earlier in some municipalities than in others [32]. Firstly, in municipalities such as Noja, which has gone from 1300 inhabitants in 1980 to 2100 in 2001, Laredo or Castro Urdiales (from 13,050 inhabitants in 1980 to 21,081 in 2001), in the last years of the twentieth and in the early twenty-first century. Then, after the first years of the XXI century, in municipalities such as Colindres (from 6900 inhabitants in 2001 to 8100 in 2011), Meruelo, and Bárcena de Cicero (from 2400 inhabitants in 2001 to 4100 in 2011), which, after the previous growth of the nuclei mentioned in the first place and being located very close to them, tend to grow later.

It is then that the *Marina Oriental* took off in importance, thanks to its strategic location, with connections to both the Basque Country and Asturias, greatly differentiating itself from the rest of the region, exploiting and transforming the soil, acquiring great importance to the linked population, especially of Basque origin, a link that has a lot to do with the secondary housing that this population has in the environment of the *Marina Oriental* of Cantabria.

All this has brought about changes in economic development, moving from an economy based on the primary sector to a tertiary and very seasonal, converting its activity to adapt to needs and new demands. The most important change occurred in the space of great tradition and rural heritage, which was dedicated almost exclusively in the past to the agricultural sector; since the seventies, when the territory was rearticulated because of the pressure of new demands and activities that generate great transformations on the territory, the territory took advantage of the productive value they possess but with new uses.

This led to a great increase in real estate in the *Marina Oriental*, with housing growth above that of population. This expansion has been generated mainly thanks to the metropolitan growth of Bilbao, extending beyond the borders of the Basque Autonomous Community itself.

All this has generated a complex urbanization process, developed in stages over time, triggering an intensification where settlement has taken place closer and closer to the coast, in a highly valued space, turning the study area into a tourist destination for a large number of people, favored by the large residential value it has and generating with it, of course, important impacts, from socio-demographic to economic, technological, and environmental, among others.

The dynamics of the *Marina Oriental* has grown above the growth of the population itself, under a model in which diffusion has prevailed over coastal spaces, with great intensity and with direct consequences on landscapes, territory, and economic activities. This has resulted in a growth in residences, which has intense especially since the nineties of the last century, favored by the good communications and the best price of the housing that we find in Cantabria in relation to that of the Basque Country, leading to a constructive furor, which has not respected, sometimes, the spaces that must be protected.

We cannot forget the importance of secondary housing in this area of the *Marina Oriental*, with percentages sometimes higher than main houses. But all this boom in secondary housing entails a series of impacts and repercussions, such as the lack of endowments and services, especially during the summer season, direct and irreversible consequences on the landscape, due to the ex-novo construction that has been developed, exceeding the capacity of reception many times and prioritizing quantity over quality, to welcome mass tourism. However, not all aspects are negative, and all this has slowed down the rural exodus that was developing in many of these coastal rural areas, increasing jobs, especially focused on trade and services, and increasing mobility and endowments.

Therefore, it has been demonstrated that this space has a territorial system forged and formed over centuries, undergoing great transformations, including social, economic, urban, and landscape transformations, especially since the middle of the last century but more intensely and deeply since the seventies of the last century. These transformations occurred in a geographical space inherited from past times, which has been modeled according to the demand that has been developing, clearly modifying its character [33,34].

Therefore, a productive redefinition confirms the importance of this space within the whole of the region [35], one of the most changed since the middle of the last century, the fruit of the intensification of urban processes, as a result of the metropolitan growth of both the region and Bilbao, in this case the one with the greatest impact on the area, driven by, to a great extent, in addition to the improvement in living conditions and the attractiveness that the Cantabrian coast possesses, the improvement in communications, in this case thanks to the construction of the Cantabrian highway, with the consequent generalization of the automobile and the lower price of Cantabrian land compared to Basque land.

7. Conclusions

As has been demonstrated throughout this article, the research has been carried out on a space on which there were hardly any previous studies but which, nevertheless, presents a great strength, being considered of great importance and relevance and being extrapolable to other spaces and territories due to the importance it possesses. This is presented as a weakness, due to the scarcity of the bibliography and the need for a more complex research work.

It is a space, which, as we have seen, has undergone a great transformation in a few decades, totally changing its image and its activity, adapting to the new residential and tourist uses that have been demanded.

A series of highly relevant findings have been discovered, highlighted, and explained throughout this article, especially within the urban framework, with cases that can be considered models within Spanish territory, with great importance of secondary housing and the related population.

It is also important to reflect on the fact that this territory must be protected and cared for, despite having experienced urban processes that are already irreversible within a totally coastal space, which it is necessary to value and protect, avoiding seasonality and encouraging again the sectors that have lost importance over time. In this case, the planning has not been specifically addressed, but it would remain open for possible articles in the future, since this is a truly interesting topic.

In addition, it is necessary to cite a series of limitations and inconveniences that we find in research of this type, especially focused on the absence of certain quantitative data in official sources, which have been solved by resorting to other sources of a local nature or companies linked to certain activities (water consumption, garbage collection...), to verify that everything developed is real and truthful.

Therefore, it is important to demonstrate the importance of this space of the *Marina Oriental*, concluding that all the processes that have been developed fit and correspond to the dynamics of the economies of the most modern countries, comparing the situation of this space with other countries both in Europe and other continents.

Funding: This research received no external funding.

Data Availability Statement: Statistical data of various nature, as indicated in the article, have been obtained from the National Institute of Statistics (https://www.ine.es; accessed on 21 October 2022). Data have also been extracted from the National Geological Institute (https://www.ign.es/web/ign/portal; accessed on 21 December 2022). and the Cantabrian government, specifically the land legislation (https://mapas.cantabria.es; accessed on 21 October 2022). Data have also been extracted from the Cadastre, especially for real estate analysis (https://www.sedecatastro.gob.es; accessed on 21 October 2022), as well as the Land Occupation Information System (http://www.siose.es/presentacion; accessed on 21 October 2022), and the Corine Land Cover project (https://land.copernicus.eu/pan-european/corine-land-cover; accessed on 21 October 2022), and field work is also important.

Conflicts of Interest: The author declares no conflict of interest.

Notes

[1] The new and multiple faces of the rural cannot be seen as a finished work. A new vision of the rural is underway, which proposes a new conception of productive activities, especially those related to agriculture, and an equally new perception of the "rural" as a heritage to be enjoyed and preserved [21].

[2] According to the National Institute of Statistics, the linked population of a municipality is defined as "the set of people who have connection with it either because they reside there, because they work or study there or because they usually spend certain periods of time there (holidays, weekends...) during the year.

[3] The Functional Urban Area (AUF), formerly known as the Large Urban Zone (LUZ), consists of a city and the municipalities that form its functional environment, specifically of work influence. The objective is to have an area with a significant part of the resident employed population that moves to work in the city under study.

[4] Occupation of rural areas by a population that has links with the city for mainly work reasons and that, thanks to the improvement in the means of communication and transport infrastructures, moves daily to it without having to change their residence.

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ISBN 978-3-0365-6553-8