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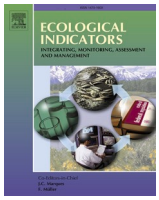

A study on the spatial and temporal dynamics of landscape spatial patterns of different types of rural communities in Taiwan

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ABSTRACT

Climate change and urbanization are the main factors causing landscape changes not only in urban areas but also in rural communities. Rural communities have economic, cultural, social, and significant ecological value. Based on the background of environmental change, this study selects three main classes of rural communities in Taiwan as the research areas. Based on the remote sensing images from 2001 to 2020 and the survey of land use status, the land transfer matrix and landscape index method were used to analyze the landscape spatial pattern changes and driving forces of rural communities. The results revealed that (1) the land use changes of the four different types of rural communities have both common features. The growth of construction land and transportation land area is a common phenomenon, and the growth rate matches the type of rural community. Forest land or farmland is the main land cover. From the perspective of land transfer analysis, it is the mutual conversion and loss of agricultural land, forest land and other land. (2) There are differences in the landscape pattern changes of the three main classes of rural communities. The production community (Dalian) pattern is progressing steadily. The ecological community (Gangbian) pattern is progressing slowly. The process of living community pattern varies greatly, while the progress of village experience type (Shuangtan) pattern is slow. The comprehensive wealth type (Seshui) pattern is developing unevenly and at a fast pace. (3) The driving force of land use change mainly comes from the policy drive of the public sector, the spatial planning system, and community development activities. This study fills in the gaps in the development of landscape spatial patterns of different types of rural communities, and provides a reference for the formulation of regulations on the spatial planning system of rural communities in Taiwan.

1. Introduction

Climate change and urbanization are the main factors causing landscape changes not only in urban areas but also in rural communities. Climate change is considered to be one of the important driving forces of land use change and environmental change (Li, et al., 2020; Smith, et al., 2020; Thapa, 2020). Climate change encompasses global warming, and natural hazards such as floods, storms, and droughts, which have adverse effects on food security, terrestrial ecosystems, and land degradation. Urbanization is one of the most significant environmental changes of the 21st century (Ning, et al., 2021; Smith, et al., 2020). Urbanization is increasing worldwide, both in the Asian region and in the European region. In the context of climate change and urbanization, the regional structure, industrial system, rural employment, farmers' lifestyle, and rural environment have all undergone tremendous changes (Li & Song, 2020; Liu & Li, 2017; Xiao, et al., 2018). Rural environmental change is reflected in changes in land use (Van Eetvelde & Antrop, 2009; Xie, et al., 2022a), reduction of semi-natural habitats (Ridding, et al., 2020), and different effects of changes in landscape function (Gottero & Cassatella, 2017; Häfner et al., 2018; Wu, et al., 2020). Furthermore, it can lead to a series of environmental problems such as water degradation, soil pollution, and biodiversity loss (Li & Song, 2020; Xiao, et al., 2018).

Rural areas have important economic, sociocultural, industrial and ecological value (Chang, 2021; Ma, et al., 2022; Peng & Wang, 2020; Qi, et al., 2022). Landscape features are defined as "distinctive, recognizable, and consistent patterns of elements in a landscape that make one landscape distinct from another" (Allen & Patton, 2013; Medeiros, et al.,

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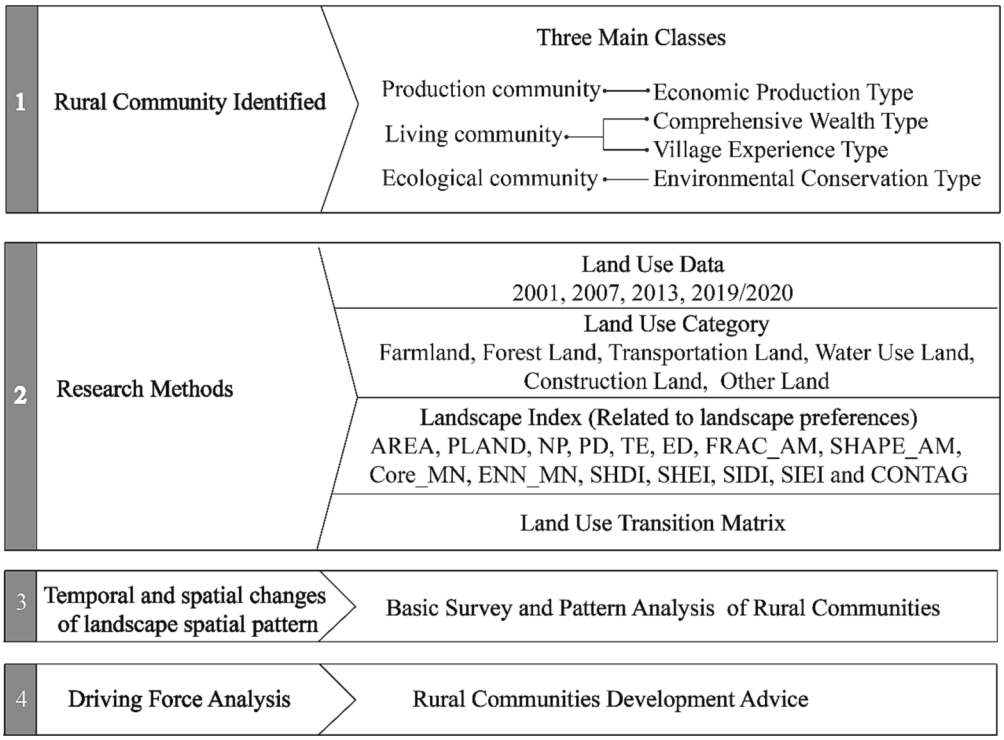

Fig. 1. Research Structure and Design.

2022). Rural landscape features contain physical landscape components (landscape type, geology, topography, soil, vegetation, etc), anthropogenic elements and components (cultural heritage, land use, field patterns, and human settlements) that make different landscapes distinct from each other (Van Eetvelde & Antrop, 2009). Furthermore, it is strongly influenced by elemental or patch composition and configuration (Medeiros, et al., 2022). Understanding rural landscape features change is critical to formulating more refined sustainable rural landscape management (Antrop, 2005; Xiao, et al., 2018).

The analysis of spatial and temporal landscape changes in rural areas is an important clue to reflect the regional development pattern (Ellis Erle, et al., 2013), which has always been a hot spot of analysis in the fields of geography, natural resources, and urban and rural planning (Xie, et al., 2022b), which can provide important and useful information for sustainable development to make rational decisions (Tu & Chen, 2020). A comprehensive assessment of changes in rural spatial and temporal dynamics will benefit the environmental management and spatial planning of the landscape (Wu, et al., 2020; Xie, et al., 2022b). The driving factors of spatiotemporal changes in rural landscapes interact with different factors at different time and space scales to produce results with different strengths(Abrantes, et al., 2016; Burgi, et al., 2005; Kristensen, et al., 2016). Among them, different factors include three major aspects, such as physical environmental factors, socioeconomic factors, legislation and policy (Kristensen, et al., 2016). Physical environmental factors include topography (slope, land type, soil, climate, hydrology) and regional location (distance to town, distance to road, distance to water system) (Li & Song, 2020; Xie, et al., 2022a; Xu, et al., 2018; Yang & Li, 2020; Kristensen, et al., 2016). Socioeconomic factors include regional industries, population, economic factors, education levels, literacy levels, and urbanisation levels (Li & Song, 2020; Xie, et al., 2022a; Xu, et al., 2018; Yang & Li, 2020). Legislation and policy factors include land ownership, land use regulations, rural development policies, and other activities (Li & Song, 2020; Xie, et al., 2022a; Xu, et al., 2018; Yang & Li, 2020; Kristensen, et al., 2016).

The number of studies on the spatiotemporal dynamics of the spatial pattern of different rural communities is limited (no clear typology of different rural areas), with studies of a single type of rural area dominating. Van der Sluis,et al., (2019a) selected six rural areas in five European countries as research sites to explore the spatial and temporal dynamics of different European rural landscape spatial patterns and changes in landscape services. The findings show that the land use and cover changes observed in the case studies over the last few decades have been relatively minor, with urbanization and afforestation processes dominating. Kristensen, et al. (2016) investigated patterns of change in landscape spatial patterns and the driving forces behind them in rural communities in three different landscape regions (*peri*-urban landscapes, areas of agricultural marginal potential, and post-socialist landscapes) in Europe between 2002 and 2012. The driving force of rural communities in the urban periphery is related to the nature of full-time/part-time/amateur farmers. The driving force of rural communities with marginal agricultural potential is related to aging populations, economic decline, and the declining status of agriculture. Post-socialist rural community driving forces are related to agricultural intensification, the expansion of large-scale farms, and small-scale farming. Krajewski, et al. (2022) selected rural communities and urban communities in Poland to investigate changes in landscape spatial patterns from 2005 to 2020. The findings show that in both communities, residents are most concerned about residential and commercial/industrial development on agricultural land. However, the main potential driving force of change is usually the intensification or expansion of agriculture. Xiao, et al. (2018) investigated the spatial variability of landscape change in three rural areas (Daxing, Quzhou, and Changshu) under rapid urbanization in eastern China from 2009 to 2012. The findings show that the landscape pattern and land use composition of the three rural areas also varied. Zhang, et al. (2023) studied the evolution of settlement systems in the alpine pastoral areas of the Tibetan Plateau and found that since 2005, the settlement system in Nagqu County has undergone a phase change from concentrated settlement to functional expansion. Medeiros, et al. (2022) discuss landscape patterns and features in the Douro region of northeastern Portugal from 1995 to 2015, with findings sharing similar trends to other Mediterranean regions,

Fig. 2. Rural Community Location Map.

driven primarily by population decline, agricultural policies, and wildfires.

Taiwan has been emphasising the development of rural communities since 1973. Until 2007, a competition for classic farming and fishing villages was held. At the same time, the Bureau of Soil and Water Conservation of the Council of Agriculture of the Executive Yuan has a clear classification of rural communities. By 2022, two editions of the Taiwan Gold Medal Rural Community Competition have been held and completed. With the development of the times, rural communities suffer from several problems such as agricultural decline, arable land abandonment, rural migration, and aging (Górka, 2018; Gullino,et al., 2018), rural landscape features are disappearing (Hanaček & Rodríguez-Labajos, 2018; Peng & Wang, 2020).However, more than 4,000 rural communities in Taiwan also face similar problems: environmental ecology has not been paid attention to, especially the development of private land, and the characteristics of rural landscapes are gradually lost (Chang, 2021; Chang, 2020). In addition, Taiwan's spatial planning system is currently in the stage of reform and construction (Lu & Cheng, 2023). 1945 to 1973 was the prototype of the system, mainly following the "Urban Planning Law" promulgated during the Japanese occupation era and its implementation rules. From 1974 to 2015, for the reform of the system, the "Regional Planning Act (RPA)" was promulgated to control the use of non-urban land, which was separated from the urban planning law and formed a dual system of urban and rural development. In 2016, the construction of the system reform began, and in May 2020, the "Spatial Planning Act (SPA)" was implemented in urban areas. Today, the SPA in non-urban areas is still under constant revision (Zhang, et al., 2020). At the same time, through literature review, the study found that research topics on rural communities in Taiwan were diverse, but limited in number, such as the landscape evaluation model (Peng & Wang, 2020), feasibility assessment of green care (Chen, et al., 2021), etc. There is still a gap in the research and discussion of the different types of rural communities, and this study can add to this part of the research contribution.

As mentioned above, rural community development has always been an important part of the Government's work. However, the rural community is facing many problems as it changes and develops over time. As a result, there have been adjustments and changes to the territorial spatial plan. Therefore, it is necessary to trace the development of the landscape pattern of rural communities that already have well-defined types in terms of spatial and temporal dynamics, in order to fill the gap in the study of different types of rural communities in Taiwan. This study investigates (1) the spatial and temporal dynamics of the spatial pattern of different types of rural community landscapes over the past 15 to 20 years, for the living, productive, and ecological types of rural communities. In turn, the suitability and compatibility of the developing situation with the type are verified. (2) The driving force of dynamic changes in the spatial patterns of living, productive and ecological rural community landscapes, providing reference materials for reforming and constructing Taiwan's non-urban spatial planning system, improving land use management policies, and promoting sustainable development.

2. Materials and methods

2.1. Research structure and design

The overall idea of this research is divided into the following four parts (Fig. 1). First, confirm the selected rural communities and their categories, mainly covering three main classes (production, living, ecological community), and specifically four subclasses (economic production type, comprehensive wealth type, village experience type, environmental conservation type). Secondly, the selected research methods include the confirmation of land use data, the classification of land use category (farmland, forest land, transportation land, water use land, construction land, other land), the selection of landscape index (related to landscape preferences), and the use of land use transition matrix. Next, the research analyzes the results of temporal and spatial changes in landscape spatial patterns, including basic survey and pattern analysis of rural communities. Finally, the analysis of driving force analysis is carried out to provide suggestions for the land space planning of non-urban areas.

2.2. Selection of research scope

The rural community is mainly divided into three main classes (production community, living community, and ecological community) and six subclasses (village experience type, economic production type, innovative agricultural type, environmental conservation type, comprehensive wealth type, and original hometown lohas type). The study area was selected from the 110 key rural communities in Taiwan as proposed by rural regeneration counties and municipalities and the Bureau of Soil and Water Conservation of the Council of Agriculture. Based on the 2007 Top 10 Classic Farming and Fishing Villages and, at the same time, the intersection of them with the winning areas of Taiwan's Gold Medal Rural Community Competition, it was determined to filter out rural communities with a good foundation. In combination with the results of the land use survey, rural communities with a slightly changed environment were selected. Ultimately, it was ensured that the rural communities selected included three main classes: production, living, and ecological communities. Therefore, the production community selected the Dalian community (an economic production community). The living community selected the Seshui community (comprehensive wealth type) and the Shuangtan community (village experience type). Ecological community selected: the Gangbian community (environmental conservation type).

(1) The living community type includes the Seshui Community of Dayan Village, Yuchi Township, Nantou County (comprehensive wealth type), and the Shuangtan Community of Shuangtan Village, Sanyi Township (village experience type). A living community is defined as a rural community with a high level of environmental functionality and standard of living. With the aim of "enhancing the overall appearance," the living community focuses on enhancing the maintenance or repair of historic buildings or facilities of landscape value. The comprehensive wealth type (life $\geq$ production $\geq$ ecology) belongs to the life type. The proportions of the three life functions are all average, and their sense of community is relatively complete. In terms of the development sequence, it still follows the sequence of life, production, and ecology of humanistic thinking. The village experience type (living $\geq$ ecology $>$ production) belongs to the living type. Although the production function is still dominated by primary and secondary industries, it is not the main source of economic income for rural residents. The reason for the higher proportion of living standards lies in the functionality of the rural community's environmental facilities and in the fact that the standard of living has reached a certain level. Under this background, the preservation of the natural environment and culture of the rural community has become an important direction.

Seshui community (Fig. 2 A) is located along road number 21 of Taiwan, surrounded by mountains, the ground looks like a lotus valley, and the altitude is about 600 to 800 m. The early years of the Seshui community were dominated by rice cultivation and betel nuts. The 1940 s saw the rise of Assam's tea, which became a major industry as the population switched to black tea cultivation. After liberation, Taiwan Tea No. 18 Red Jade became the representative of its agricultural products. After the 921 earthquake, black tea and other foodstuffs continued to be its specialty. The community also has natural white fairy soil, which is an excellent material for pottery, and pottery is the community's trademark. Bamboo is also a local specialty, preserved in everything from traditional architecture and everyday objects to the art of bamboo weaving. However, following the 921 earthquake, the neighborhood was severely devastated and replaced with new structures that were known as the "Little Switzerland of Taiwan" because of their white exteriors, blue roof tiles, and pitched roofs.

Table 1
Land Use Category.

Serial number	Classification name	Different land uses included in each category
1	Farmland	Farmland, paddy fields, dry fields, orchards, aquaculture, animal husbandry, and agricultural related facilities, etc.
2	Forest land	Coniferous forests, broad-leaved forests, bamboo forests, mixed coniferous and broad-leaved forests, shrub forests, pending forests, nurseries, and other woodlands, etc.
3	Transportation land	Airports, ports, general railways, high-speed railways, MRT, roads, agricultural roads, and related facilities, etc.
4	Water use land	Rivers, wetlands, embankments, ditches, cisterns, waterways, sandbars, beaches, and water conservancy structures.
5	Construction land	Commercial buildings, industrial buildings, residential and hard pavement in front of houses, manufacturing buildings, storage buildings, public buildings, religious buildings, schools, and other buildings, etc.
6	Other land	Grassland, bare land, funeral facilities, park green space, sports field, shrub wasteland, sandy land, artificially changed the land and idle land, etc.

Shuangtan community (Fig. 2 B) is located in the hilly area of Guandao Mountain, 700 m above sea level, with county road 130 running through it. The residents are mainly Hakka people. The community's tranquil natural landscape and traditional woodcarvings have attracted many artists. Most of the residents are still involved in woodcarving, followed by farming. It also features an old charcoal road from the early days, authentic Hakka food culture, wood carving and painting, face painting, Hakka cultural painting, and other DIY activities. The Community Village Regeneration Project aims to "create a happy Shuangtan through the creation of an agricultural art and wood art village", to create a happy village and craft village with the rebirth of old settlements, the revitalization of old and new industries, the promotion of the forest industry, and the sustainable development of the ecology, thereby improving people's lives.

(2) The productive community selected in this study is the Dalian community (economic production type) in Tianwei Township, Changhua County. Dalian community (Fig. 2 C) is located in the western plains along the side of Provincial Highway 1. A production community is defined as a community whose main direction of development is the enhancement, maintenance, and improvement of the living conditions of the production environment. Therefore, basic agricultural production and monitoring of public facilities are established at all stages of production and marketing. The production community is actively building up a professional production and sales area with integrated production and sales and is focusing on the establishment of diversified marketing channels. The economic production type (production > life > ecology) belongs to the production type. It utilizes the land management form and takes agricultural production as the community's livelihood, and the production and living functions are the main development characteristics. Among them, the development of the primary and secondary industries is greater than the function of life. In addition, due to its location, environment, and development characteristics, its ecological nature is not the main focus.

The community is named after the sickle made by the ancestors to reclaim wasteland. Its flower cultivation history can be traced back to the Qing Dynasty. During the Japanese occupation period, its industry was already impressive, which laid the foundation for the development of the community's flower industry. The community offers a wide range of activities and features, such as bike rides, night tours of the chrysanthemum, and flower auction centers.

(3) The ecological community type selected the Gangbian community (environmental conservation type) in Suao Town, Yilan County. The Gangbian community (Fig. 2 D) is located at the southernmost end of the Lanyang Plain, bordering the northernmost end of the Central Mountains, and is a community with a coastline. The ecological community is defined as one in which improvements in hardware and equipment include the upgrading of living environment facilities and conditions. The environmental conservation type (ecology ≥ production ≥ living) belongs to the ecological type. This kind of community is oriented by its environmental and ecological characteristics, and ecological and production functions are the main and secondary items. However, the proportion of ecological functions is far greater than the importance of production functions and life functions. Its community has a small number of primary and secondary industries, and its economic income comes from tertiary industries, including homestay experiences and ecological education and interpretation.

The community originally consisted of several settlements around the wetland, was rich in offshore fishing resources, and was a traditional community living on tractors and farmland. The 1970 s saw the development of cultural and economic activities featuring the traditional maritime culture of tug-of-war, such as tug-of-war dance dramas and tug-of-war competitions, which added to the vibrancy of the community. Later, due to social changes and wastewater pollution, the fisheries resources dwindled, and the community's population was faced with changing jobs, emigration, and aging. In 2001, the "eco-community" development axis has been introduced to develop sustainable communities. The community is one of the important wetlands recognized by the International Wetland Conservation Alliance. It covers an area of 102 ha and is a dry port bird sanctuary, where more than 170 species of birds inhabit. In recent years, the community has successively proposed rural regeneration plans such as the "Green and Resilient Endless Port".

2.3. Data collection

The data for this study were obtained from orthophotos published by the Institute of Agricultural and Forestry Aerial Surveying, Council of Agriculture, Executive Yuan, with an image resolution of 5 M. The image standard for image selection is that the aerial photo has the lowest cloud cover (0 %), and the community boundary range is the simplified version of the rural regeneration range released in 2018. The collected remote sensing image data from 2001 to 2021, the 20 years are divided into three six-year periods (2001, 2007, 2013, 2019/2020) for discussion. To ensure the validity of the drawings obtained, the study was also accompanied by a field survey to document the land conditions and check the changes in the land. In addition, two researchers used ArcGis to decode and analyze the remotely sensed images, and the decoded maps were proofread using the digitized maps from the Bureau of Soil and Water Conservation, Council of Agriculture, Executive Yuan, as a reference to ensure their accuracy. After comparing the community boundaries of different periods, it is found that the community boundaries of Seshui, Gangbian, and Dalian communities have not changed. Only the rural regeneration boundary of Shuangtan community is slightly smaller than the original community boundary, and the community boundary range has no effect on the study. However, due to the limitation of its image data, there will be some deviations in the image data. For example, the map data of the third phase of Seshui Community can only be selected in 2011, because the map data in 2012 and 2013 is cloudy. In addition, there is no 2001 map for Dalian community for research use, so the research period for this community is from 2007 to 2020.

2.4. Extraction of land use type information

The classification of land use is based on the accuracy of the map, the environmental characteristics of the study area, and the needs and objectives of the study. Xiao, et al. (2018) classify rural land into three main categories, namely farmland, semi-nature land, and construction land. Van der Sluis,et al., (2019a) classify land in the Roskilde into seven

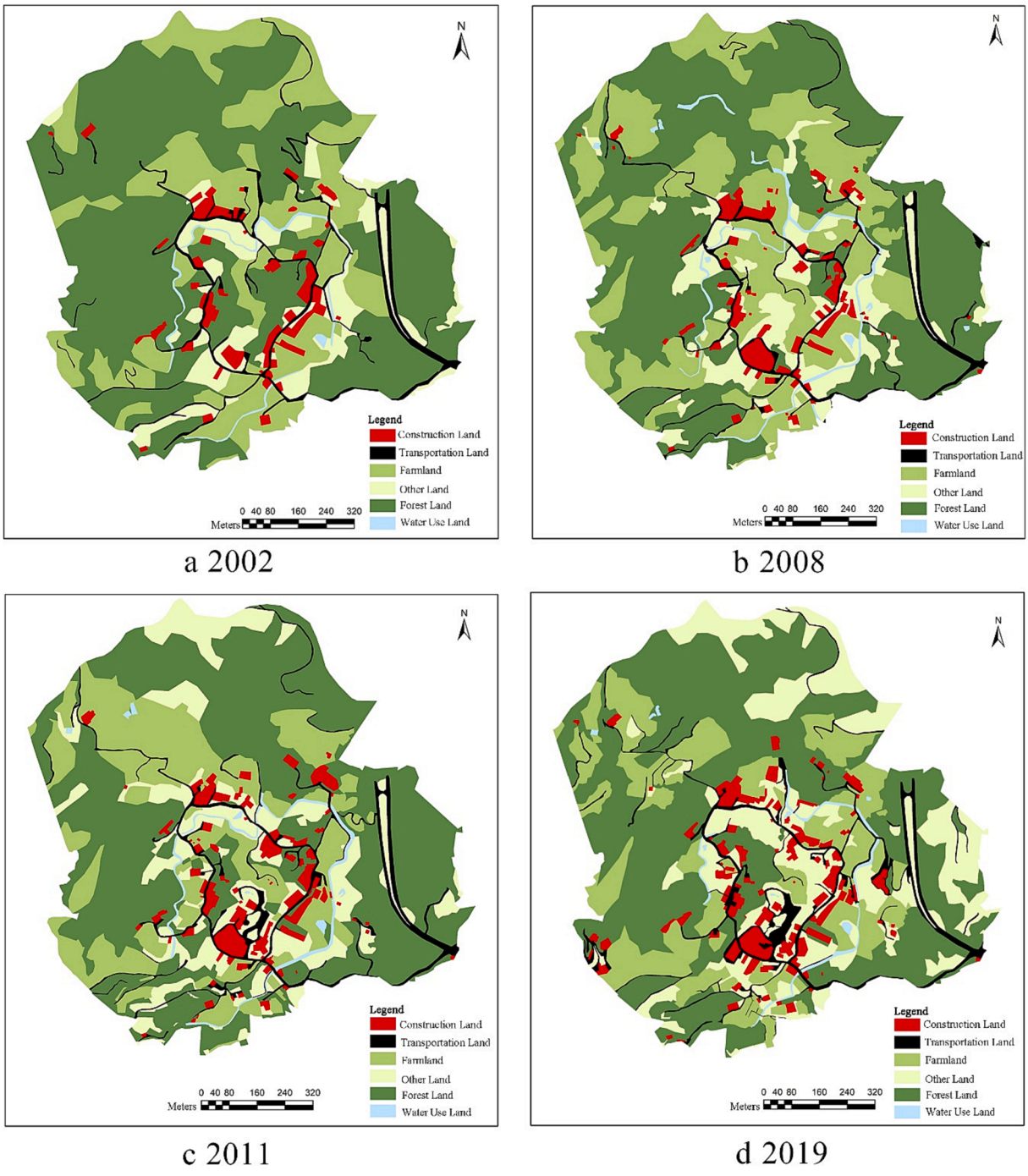

Fig. 3. Seshui Community Landscape Spatial Pattern.

categories: settlement, lake, forest, grassland, wetland, cropland, and sea. Wang and Wen (2021) classify traditional villages in forest areas into six categories: forestland, grassland, arable land, waterbody, artificial pavement, and wetland. Liu, et al. (2014) classify village-scale rural land in Yucheng into seven categories: farmland, woodland, rural settlements, rural facilities land, transportation, waterbody, and unused land.

This study is based on the survey method of the current state of land use (Construction Department of the Ministry of the Interior of the Republic of China, 2019). Considering the accuracy of the drawings and the environmental survey of land use forms through rural communities in Taiwan, land use was classified into six categories: farmland, forest land, transportation land, water use land, construction land, and other land (Table 1). The six land use categories were considered sufficient for this study.

2.5. Land use transition matrix

To gain a better understanding of the inter-transformation relationships between various land-use landscape types, a transition matrix was chosen to reflect the specific situation of the landscape type structure in the study area and the mutual transfer of various landscape types. Therefore, the transition matrix can analyze the source, destination and type composition of landscape type transition (Xu, et al., 2017).

Table 2
Land use in Seshui Community.

Time	2002		2008		2011		2019	
Category	**AREA (ha)**	**PLAND**	**AREA (ha)**	**PLAND**	**AREA (ha)**	**PLAND**	**AREA (ha)**	**PLAND**
Construction land	3.80	3.45 %	4.34	3.94 %	5.09	4.62 %	5.97	5.42 %
Transportation land	5.09	4.62 %	4.87	4.42 %	5.72	5.19 %	6.56	5.95 %
Farmland	28.73	26.08 %	34.20	31.04 %	25.02	22.71 %	23.59	21.41 %
Other land	9.96	9.04 %	12.14	11.02 %	16.95	15.38 %	22.67	20.58 %
Forest land	61.56	55.87 %	52.84	47.96 %	55.86	50.70 %	50.31	45.66 %
Water use land	1.04	0.94 %	1.79	1.62 %	1.54	1.40 %	1.08	0.98 %
Total	110.18	100.00 %	110.18	100.00 %	110.18	100.00 %	110.18	100.00 %

Table 3
Land use transition matrix of Seshui community from 2002 to 2019.

	Construction land	Transportation land	Farmland	Other land	Forest land	Water use land	**2002 Total**
Construction land	2.79	0.26	0.15	0.43	0.16	0.01	3.80
Transportation land	0.14	3.35	0.45	0.45	0.66	0.04	5.09
Farmland	1.26	1.13	10.70	10.17	5.29	0.12	28.73
Other land	1.17	0.43	1.29	4.17	2.61	0.30	9.96
Forest land	0.60	1.36	10.91	7.18	41.42	0.09	61.56
Water use land	0.01	0.04	0.09	0.24	0.14	0.53	1.04
2019 Total	5.97	6.56	23.59	22.67	50.31	1.08	110.18
Unit:ha							

2.6. Selection of landscape index

There is a correlation between landscape index and landscape preference. The land cover structure of the landscape is the basic element, and the landscape index is the digitization of its structure and has an impact on landscape perception and perception (Giles & Trani, 1999). Crawford (1994) and Palmer (1997) proposed that spatial indicators commonly used in landscape ecology can be used as indicators of landscape preference. Smardon, et al. (1986) and Franco, et al. (2003) pointed out that there is a significant correlation between landscape diversity index and landscape preference. Palmer (2004) found that the landscape index can explain most of the changes in landscape preference and perception, and ED has a significant positive correlation with landscape value. Gonzalo, et al. (2006) explored the Mediterranean climate landscape and found that the SIEI was positively correlated with the beauty of the landscape within a 1 km2 viewing area. In the 0.25 km2 viewing area, NP, SIDI, and SIEI were negatively correlated with legibility. Patch shape was correlated with double pairs of DFLD, CONT, and SIEI, and landscapes with irregular shapes had higher visual complexity. Dramstad, et al. (2006) found that SHDI, PR, NP, TE, and AREA are positively correlated with landscape preference. Fry, et al. (2009) pointed out that the coherence, complexity, scale, naturalness, and ecological index in landscape preference have commonality. For example, coherence is correlated with PR and PLAND; complexity is correlated with SIEI, dominance index, shape richness index, AREA, heterogeneity index, ED, and sprawl index; visual scale is correlated with PLAND, AREA, and ENN_MN; and naturalness is correlated with PLAND and FRAC. Schirpke, et al. (2013) studied mountain landscapes and found that shape complexity (SHAPE_MN, SHAPE_MD, FRAC_MN, FRAC_MD) and landscape diversity (SHDI, SHEI, SIDI, MSIDI, SIEI, MSIEI) are positively correlated with scenic beauty, CONTAG is negatively correlated with scenic beauty. Schirpke, et al. (2021) studied the impact of past landscape changes on the aesthetic landscape value of the European Alps, they found that MSIEI had a significant negative impact on aesthetic value; AREA_AM and SHAPE_CV had a significant positive impact on aesthetic value.

The selection of landscape indicators, first of all, needs to ensure the comprehensiveness of the landscape index, which needs to cover eight categories (area index, density size and difference, edge index, shape index, core area, proximity, diversity index, and sprawl index). Selecting more comprehensive indicators is of great significance for analyzing the spatial and temporal dynamic changes of rural communities. Second, it is necessary to select a consensus landscape index related to landscape preference (Appendix A. 1). Because follow-up research of this study needs to be combined with landscape preference. Next, to ensure the comprehensiveness of the landscape index, Core_MN and SHEI are added. Finally, selected landscape indices include AREA, PLAND, NP, PD, TE, ED, FRAC_AM, SHAPE_AM, Core_MN, ENN_MN, SHDI, SHEI, SIDI, SIEI, and CONTAG. After the selection of indicators is completed, the landscape indicators required for this study are classified, and their scales and meanings are explained, see Appendix A. 2.

2.7. Graphic processing

The research takes one year as the base period, and the figure for each period is obtained through the following procedures. The land use map is an image processed from satellite imagery using ArcGIS 10.5 software. Using manual visual interpretation, valuation information for land use maps is created through a series of operations such as map tessellation, cropping, layer creation, linear editing, surface transformation, raster conversion, and map production. However, for the accuracy of drawing processing, this manuscript was processed with ArcGIS. Starting with the earliest year, stack drawings of different years, carefully check each area and change the category boundaries and classifications of changes. For example, if the land category in a certain area has not changed, the boundary line of the category will not change due to the change of the year, thus reducing the error. If each year were to be recreated, its accuracy would be uncertain and differences would accumulate.

3. Results

3.1. Analysis of land use in four different types of communities

3.1.1. Living community- Seshui community

Through Fig. 3 the land use change of Seshui community from 2002

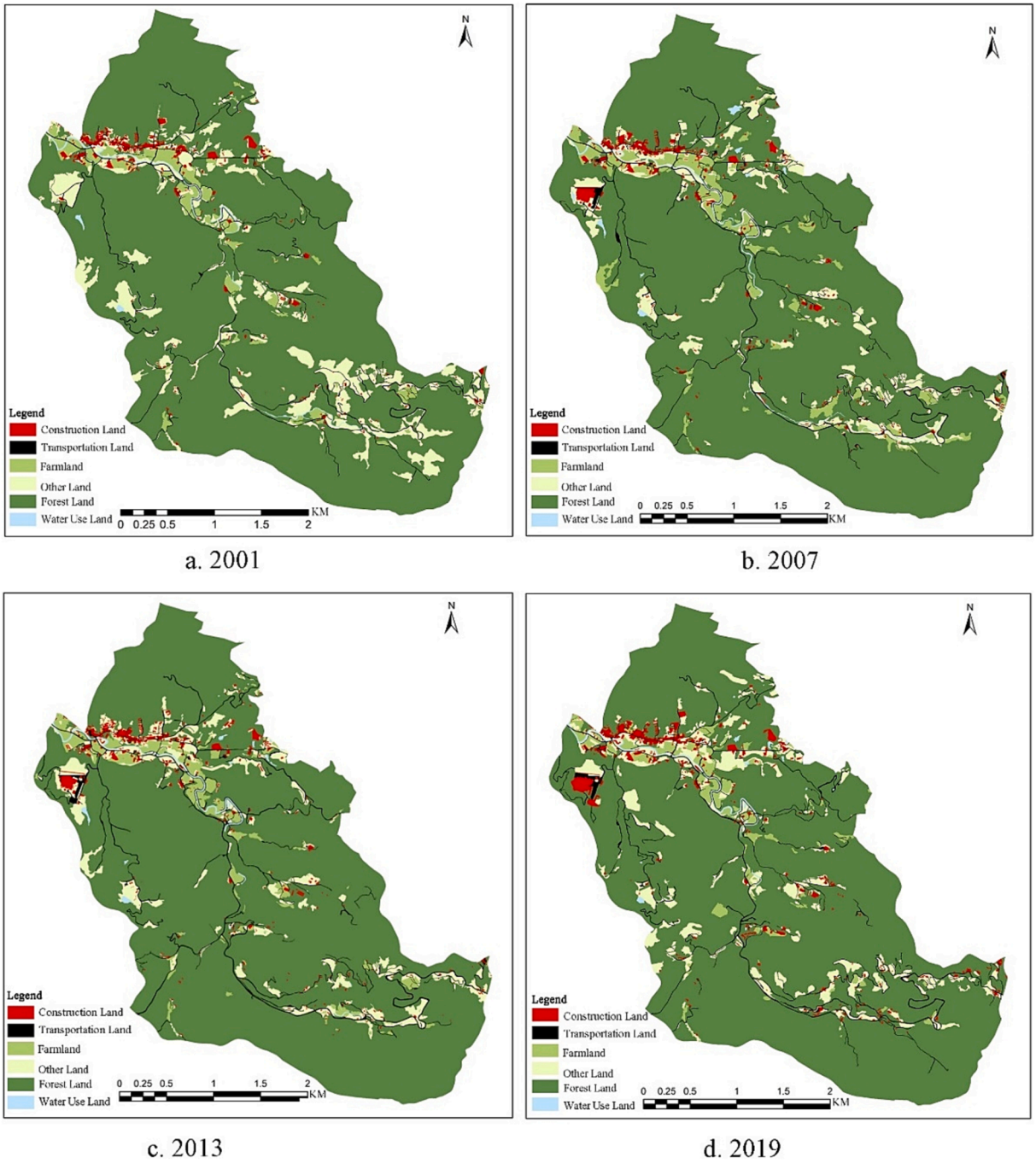

Fig. 4. Shuangtan Community Landscape Spatial Pattern.

Table 4
Land use in Shuangtan community.

Time	2001		2008		2013		2019	
Category	**AREA (ha)**	**PLAND**	**AREA (ha)**	**PLAND**	**AREA (ha)**	**PLAND**	**AREA (ha)**	**PLAND**
Construction land	17.65	1.33 %	20.60	1.55 %	20.61	1.55 %	28.99	2.18 %
Transportation land	27.76	2.09 %	33.33	2.51 %	38.16	2.87 %	39.53	2.97 %
Farmland	40.99	3.08 %	60.55	4.55 %	45.67	3.43 %	37.78	2.84 %
Other land	135.20	10.17 %	82.61	6.21 %	84.70	6.37 %	100.38	7.55 %
Forest land	1101.43	82.84 %	1122.96	84.46 %	1132.68	85.19 %	1115.94	83.93 %
Water use land	6.59	0.50 %	9.59	0.72 %	7.82	0.59 %	7.02	0.53 %
Total	1329.64	100 %	1329.64	100 %	1329.64	100 %	1329.64	100 %

Table 5
Land use transition matrix of Shuangtan community from 2001 to 2019.

	Construction land	Transportation land	Farmland	Other land	Forest land	Water use land	**2001 Total**
Construction land	13.88	0.55	0.25	1.60	1.28	0.08	17.65
Transportation land	0.68	24.02	0.13	0.63	2.26	0.04	27.76
Farmland	1.60	1.08	22.33	10.38	5.51	0.10	40.99
Other land	8.12	5.12	8.24	47.51	64.89	1.31	135.20
Forest land	4.70	7.47	6.82	40.20	1041.41	0.83	1101.43
Water use land	0.01	1.28	0.00	0.05	0.60	4.65	6.59
2019 Total	28.99	39.53	37.78	100.38	1115.94	7.02	1329.64
Unit:ha							

to 2019 can be seen. The total area of the community is 110.18 ha. Looking at the land cover in each year (Table 2), the areas of construction land, transportation land, other land and water use land have increased by 1.97 %, 1.33 %, 11.54 %, and 0.04 % respectively. The loss of forest and farmland is more serious. Forest land is the primary land cover type, farmland is secondary, and followed by the category of other land.

From Table 3, we can see the mutual conversion of each year and each category of land. The changed area of construction land was 3.18 ha, and the area of farmland and other land transferred to it was the most,1.26 and 1.17 ha. The area of changed transportation land was 3.21 ha, and the area of forest land and farmland transferred to it was the most, 1.36 and 1.13 ha. The changed area of farmland was 12.89 ha, and the area of forest land and other land transferred to it was the most, 10.91 and 1.29 ha. The changed area of other land was 18.50 ha, and the area of farmland and forest land transferred to it was the most, 10.17 and 7.18 ha. The changed area of forest land was 8.89 ha, and the area of farmland and other land transferred to it was 5.29 and 2.61 ha. The changed area of water use land was 0.05 ha, and other land and farmland transferred to construction land was 0.30 and 0.12 ha. It can be seen that the transfer of various types of land in the community is the mutual transformation of farmland, forest land, and other land.

3.1.2. *Living community- Shuangtan community*

Fig. 4 shows the land use change of Shuangtan community from 2001 to 2019. The total area of the community is 1329.64 ha. Overall observation of land cover in each year (Table 4), forest land is the main land cover type accounting for about 80 %, and other land use is the second. As of 2019, transportation land replaced farmland as the third land cover type. Compared with 2001, the area of construction land, transportation land, forest land, and water use land increased by 0.85 %, 0.88 %, 1.09 %, and 0.03 % respectively. The area of farmland and other land use decreased by 0.24 % and 2.62 % respectively.

From Table 5, we can see the mutual transformation of each stage and each type of land. Compared with 2001, the area of construction land changed by 15.10 ha. Other land and forest land transferred to construction land were the largest, 8.12 and 4.7 ha respectively. The changed area of transportation land was 15.51 ha, and the area of forest land and other land transferred to it was the largest, 7.47 and 5.12 ha respectively. The area of forest land change was 74.54 ha, and the area of other land and farmland transferred to forest land were the largest, 64.89 and 5.51 ha respectively. The changed area of water use land was 2.36 ha, and the area of other land and forest land transferred to water use land were the largest, 1.31 and 0.83 ha respectively. The changed area of farmland was 15.45 ha, and other land and forest land were converted into farmland the most, 8.24 and 6.82 ha respectively. The area of other land changes was 52.86 ha, and forest land and farmland were converted into other land-uses the most, respectively 40.20 and 10.38 ha. It can be seen that the transfer of various types of land in the community is the mutual transformation of farmland, forest land, and other land.

3.1.3. *Productive Dalian community*

Through Fig. 5, we can see the land use change of Dalian community from 2007 to 2020. The total area of the community is 143.95 ha, see Table 6 for the land cover of each year. The area of construction land, transportation land, and farmland have increased, while other land, forest land, and water use land have decreased. The land cover of the community has changed in three periods, and the top three categories are farmland, forest land, and other land in 2007; farmland, other land, and forest land in 2013; farmland, forest land, and other land in 2020.

From Table 7, we can see the mutual transformation of different periods and different types of land. The changed area of construction land was 6.97 ha, and the areas transferred to it from farmland and other land were the largest, 2.68 and 2.58 ha respectively. The changed area of transportation land was 7.73 ha, and the area of other land and farmland transferred to it was the largest, 2.82 and 2.52 ha respectively. The changed area of farmland was 25.92 ha, and the area of forest land and other land transferred to it was the largest, 12.51 and 9.30 ha respectively. The changed area of other land use was 12.66 ha, and the area of farmland and forest land transferred to it was the largest, 6.35 ha and 4.00 ha respectively. The changed area of water use land was 0.13 ha, and the areas of farmland and forest land transfer were 0.07 and 0.05 ha respectively.

3.1.4. *Ecological Gangbian community*

Through Fig. 6, we can see the land use change of Gangbian community from 2001 to 2018. The total area of the community is 299.37 ha. Judging from the land cover of each stage Table 8, the area of construction land, water use land, transportation land and other land has increased, while the area of forest land and farmland has decreased. Forest land was its main land cover type. Before 2013, farmland was the secondary land cover type. After 2013, other land became the secondary land cover, and farmland was the third type of land cover.

From Table 9, we can see the mutual conversion of different stages and different types of land. The changed area of construction land was 5.06 ha, and other land and forest land were transferred to it the most, 2.13 and 1.36 ha respectively. The changed area of transportation land was 3.96 ha, and other land and forest land were transferred to it the most, 1.47 and 1.44 ha respectively. The changed area of farmland was 11.89 ha, and forest land and other land were transferred to it the most, 6.80 and 4.25 ha respectively. The changed area of other land was 30.29 ha, and the forest land and farmland were transferred to it the most, 13.03 and 12.64 ha respectively. The changed area of forest land was 10.90 ha, and other land was transferred to it the most, which was 6.92 ha. The changed area of water use land was 3.60 ha, and other land was transferred to it the most, which was 2.57 ha. It can be seen that the transfer of various types of land in the Gangbian community is the mutual conversion and loss of farmland, forest land and other land.

3.1.5. *Land use in different types of rural communities*

Table 10 can be used for comprehensive analysis. From 2001 to 2020, the land use changes of four different types of rural communities have something in common. Ecological land includes forest land,

Fig. 5. Dalian Community Landscape Spatial Pattern.

grassland, water use land, and unused land. The proportion of ecological land in ecological rural towns is the largest, followed by farmland. Agricultural production-oriented rural towns have a large proportion of ecological land and farmland. In this study, according to the classification standards of rural communities in 2011, living communities are suitable for the development of construction land and roads, productive communities are suitable for the development of farmland, and ecological communities are suitable for the development of forest land, other land and water use land. (1) From the perspective of land use analysis, the growth of construction land and transportation land area in the four communities is a common phenomenon. The order of growth rate of construction land from high to low is Seshui community (living community) > Dalian community (productive community) > Shuangtan community (living community) > Gangbian community (ecological community). The order of growth rate of transportation land area from high to low is Dalian Community (productive community) > Seshui

Table 6
Land use in Dalian community.

Time	2007		2013		2020	
Category	**AREA (ha)**	**PLAND**	**AREA (ha)**	**PLAND**	**AREA (ha)**	**PLAND**
Construction land	21.03	14.60 %	18.32	12.72 %	22.60	15.70 %
Transportation land	12.23	8.51 %	15.11	10.50 %	16.55	11.50 %
Farmland	53.17	36.94 %	51.21	35.57 %	57.46	39.92 %
Other land	23.41	16.26 %	29.94	20.80 %	17.36	12.06 %
Forest land	33.70	23.41 %	29.03	20.16 %	29.80	20.70 %
Water use land	0.41	0.28 %	0.36	0.25 %	0.18	0.13 %
Total	143.95	100 %	143.95	100 %	143.95	100 %

Community (living community) > Shuangtan Community (living community) > Gangbian Community (ecological community). Therefore, it can be found that the growth rate of construction and transportation land matches the type of rural community. From the perspective of land cover types, forest land or farmland in each community is the most important land cover, but each community has its own characteristics. In Seshui community and Gangbian community, forest land, farmland and other land are the top three main land covers. Farmland, forest land, and construction land in Dalian community are the first three main land covers. Forest land, other land, and transportation land in Shuangtan community are the first three main land covers. From the perspective of land transfer analysis, it is the mutual conversion and loss of farmland, forest land, and other land.

3.2. Analysis of landscape spatial pattern of four different types of communities

3.2.1. Living community- Seshui community

Table 11 shows the overall changes of the Seshui community in the four periods. From 2002 to 2019, the patch density and edge index

Table 7
Land use transition matrix of Dalian community from 2001 to 2019.

	Construction land	Transportation land	Farmland	Other land	Forest land	Water use land	**2007 Total**
Construction land	15.63	0.70	2.60	1.25	0.84	0.00	21.03
Transportation land	0.44	8.82	1.49	0.87	0.61	0.00	12.23
Farmland	2.68	2.52	31.54	6.35	10.01	0.07	53.17
Other land	2.58	2.82	9.30	4.70	4.00	0.01	23.41
Forest land	1.27	1.67	12.51	4.00	14.20	0.05	33.70
Water use land	0.00	0.01	0.01	0.20	0.15	0.05	0.41
2020 Total	22.60	16.55	57.46	17.36	29.80	0.18	143.95

Unit: ha

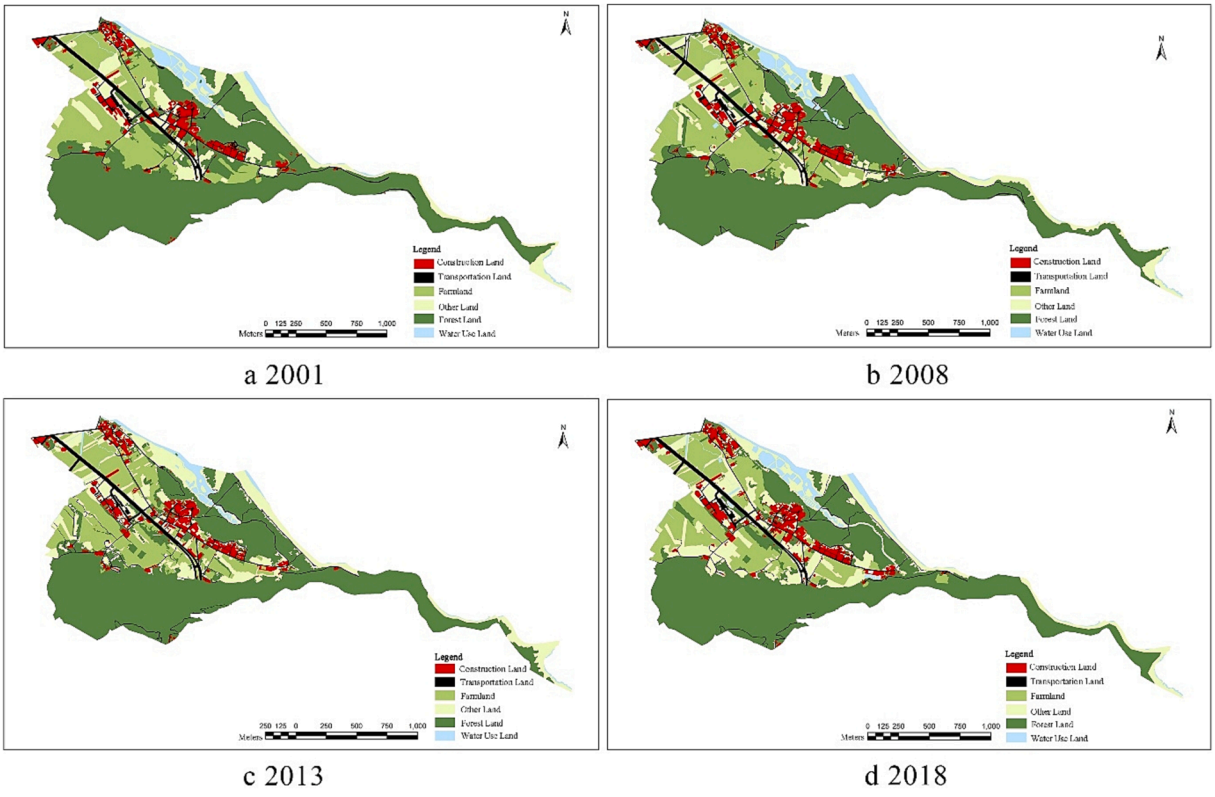

Fig. 6. Gangbian Community Landscape Spatial Pattern.

Table 8
Land use in Gangbian community.

Time	2001		2008		2013		2018	
Category	**AREA (ha)**	**PLAND**	**AREA (ha)**	**PLAND**	**AREA (ha)**	**PLAND**	**AREA (ha)**	**PLAND**
Construction land	14.25	4.76 %	15.93	5.32 %	15.96	5.33 %	16.29	5.44 %
Transportation land	14.66	4.90 %	16.19	5.41 %	16.69	5.58 %	14.69	4.91 %
Farmland	53.75	17.95 %	55.96	18.69 %	51.02	17.04 %	49.41	16.50 %
Other land	43.29	14.46 %	43.00	14.36 %	54.29	18.13 %	56.25	18.79 %
Forest land	162.6	54.31 %	155.75	52.02 %	154.14	51.49 %	150.66	50.33 %
Water use land	10.82	3.61 %	12.55	4.19 %	7.27	2.43 %	12.07	4.03 %
Total	299.37	100 %	299.37	100 %	299.37	100 %	299.37	100 %

Table 9
Land use transition matrix of Gangbian community from 2001 to 2018.

	Construction land	Transportation land	Farmland	Other land	Forest land	Water use land	**2001 Total**
Construction land	11.23	0.49	0.32	1.44	0.76	0.01	14.25
Transportation land	1.16	10.73	0.38	1.21	1.12	0.06	14.66
Farmland	0.41	0.55	37.52	12.64	1.89	0.76	53.75
Other land	2.13	1.47	4.25	25.96	6.92	2.57	43.29
Forest land	1.36	1.44	6.80	13.03	139.76	0.20	162.60
Water use land	0.00	0.01	0.14	1.97	0.21	8.47	10.82
2018 Total	16.29	14.69	49.41	56.25	150.66	12.07	299.37

Unit: ha

Table 10
Different types of land use in rural communities.

		Seshui Community	**Dalian Community**	**Gangbian Community**	**Shuangtan Community**
Community Type		Comprehensive Wealth Type/ Living Community	Economic production/ Production Community	Environmental Conservation Type/ Ecological Community	Village Experience Ttype / Living Community
CommunityArea		110.18 ha	143.95 ha	299.37 ha	1329.64 ha
Land Use Situation	**Area Increase**	Construction land(1.97 %) Transportation land(1.33 %) Other land(11.54 %) Water use land(0.04 %)	Construction land(1.09 %) Transportation land(3.00 %) Farmland(2.98 %)	Construction land(0.68 %) Transportation land(0.01 %) Other land(4.33 %) Water use land(0.42 %)	Construction land(0.85 %) Transportation land(0.89 %) Forest land(1.09 %) Water use land(0.53 %)
	Area Decrease	Forest land(10.21 %) Farmland(4.67 %)	Other land(4.2 %) Forest land(2.71 %) Water use land(0.16 %)	Forest land(3.99 %) Farmland(1.45 %)	Farmland(0.24 %) Other land(2.62 %)
Main Land Cover Category		1、Forest land 2、Farmland 3、Other land	1、Farmland 2、Forest land 3、Construction land	1、Forest land 2、Farmland 3、Other land	1、Forest land 2、Other land 3、Transportation land
Land Use Transfer		It is the mutual conversion and loss of farmland, forest land and other land.			

Table 11
Landscape level index of Seshui community.

Index Field	**Landscape Index**	**2002**	**2008**	**2011**	**2019**	**Annual Trend**	**General Trend**
Density	**NP**	159	213	241	252	↑↑↑	↑
	PD	144.25	193.23	218.54	228.80	↑↑↑	
Edge	**TE**	43,233	52,512	54,754	58,630	↑↑↑	↑
	ED	392.23	476.39	496.51	532.32	↑↑↑	
Shape	**SHAPE_AM**	3.49	3.30	3.75	3.97	↓↑↑	↑
	FRAC_AM	1.20	1.21	1.22	1.22	↑↑→	
Core Area	**CORE_MN**	0.38	0.25	0.22	0.20	↓↓↓	↓
Proximity	**ENN_MN**	21.33	19.74	17.45	16.37	↓↓↓	↓
Spread	**CONTAG**	64.83	61.81	60.80	58.96	↓↓↓	↓
Diversity	**SHDI**	1.20	1.29	1.32	1.38	↑↑↑	↑
	SHEI	0.67	0.72	0.74	0.77	↑↑↑	
	SIDI	0.61	0.66	0.66	0.70	↑→↑	
	SIEI	0.73	0.79	0.79	0.84	↑→↑	

showed an upward trend, and NP, PD, TE and ED increased to 252, 228.80, 58630, and 532.32, indicating that the degree of landscape fragmentation in this community has increased. The shape index also increased gradually over the years, with SHAPE_AM increasing to 3.97 and FRAC_AM increasing to 1.22. Although the increase of these two indicators is not large, it shows that the shape of the patch tends to be

Table 12
Landscape level index of Shuangtan community.

Index Field	Landscape Index	2002	2008	2011	2019	Annual Trend	General Trend
Density	NP	793	898	986	895	↑↑↓	↑
	PD	59.64	67.54	74.16	67.31	↑↑↓	
Edge	TE	256,986	271,696	266,824	283,469	↑↓↑	↑
	ED	193.28	204.34	200.67	213.19	↑↓↑	
Shape	SHAPE_AM	5.96	5.93	6.09	6.40	↓↑↑	↑
	FRAC_AM	1.23	1.23	1.22	1.23	→↓↑	→
Core Area	CORE_MN	1.00	0.88	0.82	0.85	↓↓↑	↓
Proximity	ENN_MN	29.41	30.18	31.61	31.10	↑↑↓	↑
Spread	CONTAG	80.67	80.94	81.64	80.62	↑↑↓	↓
Diversity	SHDI	0.66	0.65	0.62	0.66	↓↓↑	→
	SIDI	0.30	0.28	0.27	0.29	↓↓↑	↓
	SHEI	0.37	0.36	0.35	0.37	↓↓↑	→
	SIEI	0.36	0.34	0.32	0.35	↓↓↑	↓

Table 13
Landscape level index of Dalian community.

Index Field	Landscape Index	2002	2008	2011	Annual Trend	General Trend
Density	NP	826	1007	793	↑↓	↓
	PD	573.77	699.57	550.90	↑↓	
Edge	TE	121,987	132,690	117,373	↑↓	↓
	ED	847.36	921.81	815.39	↑↓	
Shape	SHAPE_AM	5.02	5.81	6.04	↑↑	↑
	FRAC_AM	1.22	1.24	1.24	↑→	
Core Area	CORE_MN	0.04	0.03	0.04	↓↑	→
Proximity	ENN_MN	11.93	10.39	14.03	↓↑	↑
Spread	CONTAG	54.22	53.37	54.77	↓↑	↑
Diversity	SHDI	1.51	1.53	1.50	↑↓	↓
	SHEI	0.84	0.85	0.83	↑↓	↓
	SIDI	0.75	0.76	0.75	↑↓	→
	SIEI	0.90	0.91	0.89	↑↓	↓

Table 14
Landscape level index Gangbian community.

Index Field	Landscape Index	2002	2008	2011	Annual Trend	General Trend	Index Field
Density	NP	347	517	649	522	↑↑↓	↑
	PD	115.91	172.70	216.79	174.40	↑↑↓	
Edge	TE	98,413	122,334	138,429	124,317	↑↑↓	↑
	ED	328.74	408.66	462.40	415.33	↑↑↓	
Shape	SHAPE_AM	4.45	5.12	5.02	4.97	↑↓↓	↑
	FRAC_AM	1.22	1.23	1.23	1.23	↑→→	↑
Core Area	CORE_MN	0.55	0.34	0.26	0.33	↓↓↑	↓
Proximity	ENN_MN	18.51	17.36	15.42	16.22	↓↓↑	↓
Spread	CONTAG	61.25	59.62	59.92	59.22	↓↑↓	↓
Diversity	SHDI	1.33	1.38	1.36	1.39	↑↓↑	↑
	SHEI	0.74	0.77	0.76	0.78	↑↓↑	
	SIDI	0.65	0.67	0.67	0.68	↑→↑	
	SIEI	0.78	0.80	0.80	0.81	↑→↑	

more complicated, still approximately square, and there may be manual intervention. The reduction of CORE_MN indicates that the core patch area is reduced. The decrease of the proximity index indicates that the distance between patches gradually decreases. CONTAG is reduced to 58.96 with moderate sprawl, implying reduced patch continuity and fragmented landscape with small and scattered patches. SHDI and SHEI, SIDI and SIEI have all increased year by year, respectively, from 1.2 and 0.67 to 1.38 and 0.77, 0.61 and 0.73 to 0.70 and 0.84, indicating that the diversity and uniformity of community landscapes are constantly improving.

3.2.2. *Living community-shuangtan community*

Table 12 shows the overall changes in the four periods of the Shuangtan community. From 2001 to 2019, both the density and the edge index have an increasing trend, with growth rates of 12.86 % and 10.31 %. NP and PD reached their peak in 2013 and then declined, while TE and ED showed a first increase, then a decrease, and then an increase, and reached their peak in 2019, indicating that the overall landscape of the community is fragmented. FRAC_AM has not changed overall, and is relatively stable at 1.23, indicating that the shape of the plaque tends to become more complicated, but it does not deviate too much from the square. CORE_MN showed a decreasing trend as a whole, and decreased to 0.85 ha, indicating that the core area of the patch decreased. ENN_MN showed an overall increasing trend, increasing to 31.10. CONTAG showed a decreasing trend as a whole, reduced to 80.62, indicating that the patch was scattered and the continuity decreased. SHDI and SHEI are generally stable, maintaining at 0.66 and 0.37; SIDI and SIEI have the same trend, with a slight decrease overall. This shows that the

Table A1
The relationship between landscape index and landscape preference.

Serial Number	Landscape Index	Relevance	Positive/ negative correlation	Sources
1	AREA	Mystery	+	Chung (2002)
		Openness	–	
		Complexity	None	Fry, et al. (2009)
		Visual scale	None	Fry, et al. (2009)
		Landscape preference	+	Dramstad, et al. (2006)
2	SIEI	Landscape beauty	+	Gonzalo, et al. (2006) ;
		Legibility	–	Schirpke, et al. (2013)
		Complexity	None	Gonzalo, et al. (2006) ; Fry, et al. (2009)
3	NP	Legibility	–	Gonzalo, et al. (2006)
		Landscape preference	+	Dramstad, et al. (2006)
4	SIDI	Legibility	–	Gonzalo, et al. (2006)
		Landscape beauty	+	Gonzalo, et al. (2006) ; Schirpke, et al. (2013)
5	PD	Landscape preference	None	Dramstad, et al. (2006)
6	SHAPE	Landscape beauty	+	Schirpke, et al. (2013)
7	CONTAG	Complexity	None	Gonzalo, et al. (2006)
		Landscape beauty	–	Schirpke, et al. (2013)
8	ED	Complexity	None	Fry, et al. (2009)
		Landscape value	+	Palmer (2004)
9	DFLD	Complexity	None	Gonzalo, et al. (2006)
10	FRAC	Naturalness	None	Fry, et al. (2009)
		Openness	+	Chung (2002)
		Landscape beauty	+	Schirpke, et al. (2013)
11	PLAND	Coherence	None	Fry, et al. (2009)
		Naturalness		Fry, et al. (2009)
		Openness		Fry, et al. (2009) ; Dramstad, et al. (2006)
12	PR	Coherence	None	Fry, et al. (2009)
		Landscape preference	+	Dramstad, et al. (2006)
13	ENN-MN	Openness	None	Fry, et al. (2009)
14	TE	Landscape preference	+	Dramstad, et al. (2006)
15	MSIEI	Landscape beauty	+/-	Schirpke, et al. (2013) ; Schirpke, et al. (2021)
16	AREA_AM	Landscape beauty	+	Schirpke, et al. (2021)
17	SHAPE_CV	Landscape beauty	+	Schirpke, et al. (2021)
18	SHDI	Landscape preference	+	Dramstad, et al. (2006)
		Landscape beauty	+	Schirpke, et al. (2013)

distribution of landscape patches in this community is uneven, dominant patches are dominant, and ecological functions are limited.

3.2.3. *Productive community-dalian community*

Table 13 shows the overall changes in the three periods. From 2007 to 2013, the density and edge index showed a downward trend overall. It

Table A2
Classification, scale, and meaning of landscape index.

Category	Name	Scale	Unit	Mean
AREA	AREA	Patch level index	ha	The larger the value, the more patches of land. This metric provides an understanding of the landscape composition and the area of each patch.
	PLAND	Landscape Category Index	%	The percentage of the patch to the landscape area shows the proportion of each type of land use.
Density	NP	Landscape Category/ Level Index	pcs	The total number of patches in the landscape, NP $\geq$ 1, no upper limit.
	PD		/ha	The number of patches per square kilometer, PD $>$ 0, no upper limit. The higher the value, the more serious the fragmentation of the landscape pattern.
Edge	TE		m	The total length of all patch edges in the landscape, TE $\geq$ 0, no upper limit.
	ED		m/ ha	ED $\geq$ 0, no upper limit. The index measures the total edge length of each type of patch. When the edge density is higher, it means that the proportion of edge length in the landscape is also longer. This is used to understand the complexity of shapes. The greater the change of ED, the higher the degree of fragmentation.
Shape	FRAC_AM		None	1 $\leq$ FRAC_AM $\leq$ 2. For a patch in two dimensions, a value greater than 1 indicates a deviation from a square or rectangle. The value tends to be close to 2, which means that the patch shape is complex.
	SHAPE_AM			SHAPE_AM $\geq$ 1, no upper limit. Its value increases with the irregularity of the patch shape; SHAPE_AM = 1 when all patches in the landscape are square.
Core area	Core_MN		ha	Core_MN $\geq$ 0, the larger the value, the more the core area.
Proximity	ENN_MN		m	The neighboring distance is the sum of the neighboring distances of similar patches, and the neighboring distance is the edge-to-edge distance. The larger the index, the more distant the patches are from each other and the higher the dispersion. The smaller the value, the closer the patches are.
Diversity	SHDI	Landscape level index	None	SHDI $\geq$ 0, no upper limit. When there is only one patch type in the landscape, SHDI = 0. The value of SHDI increases when the patch type increases or the proportion of area occupied by each type of patch tends to be close to each other.

(*continued on next page*)

Table A2 (*continued*)

Category	Name	Scale	Unit	Mean
	SHEI			When SHEI tends to 1, it means that the landscape patches are evenly distributed and there are no obvious dominant patches with good ecological functions; lower SHEI value tends to 0, which means that the landscape patches are unevenly distributed and there are a few dominant patches with limited ecological functions.
	SIDI			The closer the value is to 1, the more advantageous the species is in the area, and the lower the value is.
	SIEI			When the landscape is composed of a single patch, the landscape is homogeneous and does not have the diversity of the landscape, and the diversity index is 0. When the number of patches increases, the index also increases.
Spread	CONTAG		%	A larger value means that the landscape has several large contiguous patches, while a lower value means that the landscape has many small and scattered patches.

shows that the degree of fragmentation of the community landscape is gradually reduced, there is a phenomenon of patch merging, and the complexity of the edge is reduced. Both SHAPE_AM and FRAC_AM show an increasing trend year by year, indicating that the shape of the patch has become more complex. CORE_MN is unchanged. Both ENN_MN and CONTAG showed a state of falling first and then rising. ENN_MN rose from 11.93 to 14.03, and CONTAG rose from 54.22 to 54.77. It means that the distance between patches becomes longer, and some patches are more continuous. SHDI, SHEI, SIDI, and SIEI did not change significantly, but decreased slightly. Although the landscape diversity and uniformity decreased, they were generally stable.

3.2.4. Ecological community -gangbian community

Table 14 shows the overall changes of the Gangbian community in the four periods. From 2001 to 2018, the patch density and edge index showed an upward trend, increasing by nearly 50.42 % and 26.32 %, respectively. It shows that the overall landscape of the community is fragmented, and the number of patches and edge density increase. The overall trend of SHAPE_AM and FRAC_AM is still increasing, indicating that the shape of the patch tends to become more complicated, and the boundary of the patch becomes slightly more complicated and tends to be square. CORE_MN, ENN_MN and CONTAG showed a decreasing trend as a whole, decreasing by 40 %, 12.73 %, and 3.31 % respectively. It shows that the patches are divided into small and scattered patches, the core area is reduced, and the distance between patches is closer. SHDI, SHEI, SIDI, and SIEI have the same trend, and they all increase overall, indicating that the diversity and uniformity of the overall environment of the community are developing towards a benign development.

3.2.5. Different types of rural community landscape index

Although the Seshui community and the Gangbian community belong to different types of rural communities, they have a high degree of similarity in terms of land use and landscape level index development. The development speed of landscape spatial patterns in Seshui community is faster than that of Gangbian community. Among the six land use situations in the two communities, the loss of forest land and farmland area is the most severe. The overall landscape shows a trend of continuous fragmentation, the shape of the patch tends to be more complex, the core area is reduced, the distance between the patches is reduced, the degree of aggregation is reduced, and there are small and scattered patches. However, the overall diversity and uniformity of its landscape continue to increase. The Seshui community is a comprehensive wealth type/living rural community, according to the ratio of three living things, life $\geq$ production $\geq$ ecology, the development of landscape space pattern in this community is unbalanced. The Gangbian community is an environmental conservation type/ecological rural community, according to the ratio of three living things, ecology $>$ production $\geq$ life. Judging from the current situation, the progress of the landscape spatial pattern of the community is slow, and the fragmentation of forest land, other land and water use land are deepened, and the shape is complex, basically moving forward in accordance with the direction of ecological development.

The Shuangtan community is a village experience type/living community, according to the ratio of three living things, living $\geq$ ecology $>$ production. Judging from the current situation, the progress of the landscape spatial pattern of this community is slow, and it develops according to the category of rural communities, and its general trend is deepening of fragmentation. The community patches are unevenly distributed, dominated by dominant species, with limited ecological functions, and limited development in both diversity and uniformity.

The Dalian community is an economic production/production community, according to the ratio of three living things, production $\geq$ living $>$ ecology. Judging from the current situation, the landscape spatial pattern of the community is stable and develops according to the category of rural communities, and the community as a whole shows a development trend of reducing the degree of fragmentation. The edge complexity of the patch is reduced, the shape of the patch is complex, the distance between the patches becomes farther, and some patches are more aggregated and continuous. Although the diversity and uniformity of the landscape have decreased, it is generally stable.

4. Discussion

4.1. Land use change in rural communities

The results of the study show that the growth rate of construction and transportation land in rural communities matches the type of rural communities. Guo, et al. (2022) also found similar findings in rural areas of the Himalayas. Although construction land expansion is a common trend in urbanization (Ridding, et al., 2020; Van der Sluis,et al., 2019a; Vimal, et al., 2012), Xiao, et al. (2018) and Guo, et al. (2022) found that the growth rate of construction land in rural areas is slow, which is consistent with the results of this study. From the perspective of land cover types, forest land or farmland in each community is the most important land cover (Wang & Wen, 2021), but each community has its characteristics. From the perspective of land transfer analysis, land use in rural communities is the mutual conversion of farmland, forest land and other land uses. The research of Wang, et al. (2022) also has similar results. Global agricultural land reduction is a general trend (Alphan, 2003; Van der Sluis,et al., 2019a; Wang & Wen, 2021), and changes in agricultural land will affect rural ecosystem services, thereby affecting human well-being (Peng & Wang, 2020). The research by Xiao, et al. (2018) found that the trend of farmland loss in the three rural areas is the same, but at different speeds, which is similar to the results of the living and ecological rural communities in this study. Van der Sluis, et al., (2019a) found that the conversion of farmland to forest or settlements was common, a result consistent with the results of the four rural communities included in this study.

4.2. Changes and driving forces of landscape spatial pattern in rural communities

The research shows, from 2001 to 2020, there are differences in the changes of landscape spatial patterns in three main classes and four subclasses of rural communities. Xiao, et al. (2018) found that there are differences in the landscape patterns of the three rural areas in eastern China, with Changshu in Jiangsu having the greatest change, followed by Daxing in Beijing, and Quzhou in Hebei having the least change. This study has similar conclusions. The process of landscape spatial pattern in production community (Dalian) is stable. The industry has also played an important role in spatial evolution. For rural areas with stable landscape spatial patterns, their economic development depends on the agricultural industry and lacks endogenous and extrinsic motivation to promote their development (Xie, et al., 2022b). Van der Sluis,et al., (2019a) in their study of agricultural production areas in western Denmark found that the area of farmland remained stable and that other land use categories experienced important changes, which is similar to the results of this study. The progress of landscape spatial pattern in ecological community (Gangbian) and living community (Shuangtan) was slow. Xie,et al., (2022b) found in their research on the rural areas of Guangdong that the rural urban landscape pattern dominated by ecology is stable. Due to the influence of topographical factors, the spatial evolution process is limited, which is similar to the results of this study. Wang and Wen (2021) found that rural areas tend to have a more stable landscape spatial pattern, and the agroforestry ecosystem presents a relatively stable landscape over time. Mountainous areas usually experience slow land use change and low development density (Ma, et al., 2018; Xie, et al., 2022b). The year 2013 was a turning point for the Gangbian, Shuangtan, and Dalian communities, where landscape fragmentation was the most prominent. However, the development of the landscape spatial pattern of living community (Seshui) is unbalanced and the development speed is relatively fast. Until 2019, it is still in the development stage of landscape fragmentation, and it is the most serious. The spatial pattern of landscape in the mid-level area has changed greatly and has become more diversified (Ma, et al., 2018).

This study believes that the driving forces for the changes in the landscape spatial pattern of rural communities mainly come from the policies of the public sector, the spatial planning system (Liu, et al., 2016; Tu & Chen, 2020), community development activities (van der Sluis, et al., 2019b). Public participation, coalitions of social organizations, and financial resources often determine outcomes in landscape spatial patterns (Hersperger, et al., 2014; van der Sluis, et al., 2019b). van der Sluis, et al. (2019b) identified two main categories of landscape drivers in rural Europe: 'policy and legislation' and 'economy and markets'. These drivers, although not negative in themselves, have mostly negative impacts on the landscape, for example, policy and economic development leading to infrastructure expansion, population change, and landscape fragmentation. Some policies have obvious positive effects and will lead to benign developments such as ecotourism.

The development of rural community policies in Taiwan started in 1958. It was not until 2000 that the Amendment to the Regulations on Agricultural Development was officially passed, which opened up the free trade of farmland and liberalized the conditions for farmland transactions and farmhouse construction (Cheng, 2012). Public land has been transferred to private land, and private land is no longer subject to government supervision (Tu & Chen, 2020). In 2000, the Agriculture Committee of the Executive Yuan formulated the "Creating a New Rural Style Plan". The plan lasted until 2008, featuring the reconstruction of rural settlements, improving the rural living environment, assisting in the construction of a new rural life circle, and shaping a new rural style. In 2001, the "Measures for Building Farmhouses on Agricultural Land" was promulgated, which greatly impacted the rural landscape, resulting in the construction of luxurious farmhouses or small-scale farmhouses. Then in 2003, the detailed implementation rules for rural land rezoning were promulgated, with the purpose of land rezoning in rural communities to rationally utilize land in rural communities and improve the community environment (Chen, 2004). In 2007, the Council of Agriculture of the Executive Yuan held a selection activity for classic farming and fishing villages. A total of 10 farming and fishing village communities were selected, and five awards were awarded and subsidized. Therefore, before 2007, life-type, ecological-type, and production-type rural communities should respond to agricultural development regulations and amendments, methods for building farmhouses on agricultural land, selection of classic farming and fishing villages, guiding policies for creating a new rural look, and self-development, etc. Hardware development is the main focus, and land conversion is relatively large. The landscape spatial pattern at this stage is in a stage of development that tends to be fragmented.

Until 2008, the land development was carried out in accordance with the "Regulations and Implementation Rules on Land Rezoning in Rural Communities" to handle the four-year demonstration plan for land redesignation in rural communities and the six-year demonstration plan for land redesignation in rural communities. In 2009, the "Rural Community Land Redesignation" was launched, with the purpose of improving the living environment in rural areas, constructing a new style of rural areas, and improving the development of rural communities. In addition, in 2009, the Bureau of Soil and Water Conservation of the Council of Agriculture of the Executive Yuan formulated the "Plan for Revitalizing the Economy and Expanding Public Construction Investment". The main work items of the plan include the preliminary planning of rural regeneration construction, participatory greening and beautification of rural living environment, and accelerating the improvement of rural basic environment. From 2009 to 2012, the Bureau of Soil and Water Conservation of the Council of Agriculture of the Executive Yuan formulated "Building a Rich New Countryside", focusing on the existing rural communities, strengthening the bottom-up joint participation system, and emphasizing the commonality of rural industries, natural ecology and living environment planning and construction. In 2010, the Council of Agriculture of the Executive Yuan began to formulate the "Rural Community Regeneration Plan 1.0″. Based on the principle of three life (life, production, and ecology), in addition to improving the hardware environment, it gradually favored software construction (encouraging young people to return to their hometowns for employment). etc. Moreover, the rural regeneration plan is divided into three phases: 2012–2015 is the first phase of rural regeneration; 2016–2019 is the second phase of rural regeneration; 2020–2023 is the third phase of rural regeneration. The first phase of rural regeneration from 2012 to 2015 has been completed. The completed content includes that the community construction began to focus on software and supplemented by hardware. The community promotes the improvement of dirty spaces, and strengthens the community to improve dirty, messy, broken and other spaces. In addition, looking at the development of Taiwan's spatial planning system, from 1974 to 2015, the "Regional Planning Act (RPA)" was implemented. The urban planning part of this code has statutory planning, and non-urban planning is regulated by land control rules (Lu & Cheng, 2023; Zhang et al., 2020). Therefore, living, ecological and productive rural communities have undergone land transformation in 2013 in response to such policies as land rezoning, building a rich new countryside, spatial planning system and rural regeneration plan, and are in the transition from hardware to software development. At this stage, the landscape spatial pattern is still in a stage of fragmented development. The landscape fragmentation phenomenon is most obvious in the Gangbian, Shuangtan and Dalian communities, while the Seshui community continues to be fragmented.

After 2013, rural communities entered a period where software development was the main focus. In 2016, the Rural Community Regeneration Project 2.0 was produced, a transformation based on the principles of three livelihood and three agriculture (life, production, ecology, agriculture, countryside, farmers). At the same time, in 2016, the Bureau of Soil and Water Conservation of the Council of Agriculture promoted Taiwan's rural areas to focus on the three life and future

planning, and selected gold medal rural activities, thus further promoting rural development. 2016–2019 is the second phase of rural regeneration. The completed content includes rural manpower and education, and the expansion of the participation of the whole people such as local governments and non-governmental organizations. To create a unique style of rural areas, to move towards the core goal of sustainable and diversified development of rural areas, specially handle the Gold Medal Rural Competition, and advocate cross-regional development of rural regeneration. 2020–2023 is the overall development goal of the third phase of the rural regeneration plan, to create a working countryside, a living countryside, a guarded countryside and a vibrant countryside. In addition, the land planning system was formally formed after the promulgation of the Land Planning Law in 2016. It was revised in 2020 and is being continuously updated (Zhang, et al., 2020). Therefore, after 2013, ecological, productive, and living (Shuangtan) rural communities focused on software development in response to the promotion of policies and activities such as the Rural Community Regeneration Plan 2.0 and the changes in the spatial planning system. The landscape spatial pattern in this stage tends to develop slowly and improve. However, the fragmentation of landscape in the living community (Seshui) is the most significant in 2019. On the one hand, in the Seshui community in recent years, the agricultural industry has changed, from bamboo and betel nuts as the main product to tea plantations, and betel nut forests have been converted into tea gardens. Agricultural industry transformation (Ma, et al., 2018) and land use conversion between farmland, orchards, nurseries, and other productive lands are the driving forces of rural change (Xiao, et al., 2018). On the other hand, because it is not far from Sun Moon Lake, it provides convenient conditions for the development of the homestay industry. As a result, the growth rate of construction land and transportation land is rapid, the loss of forest land and farmland is converted into other land use, etc., and abandoned farmland and idle land have appeared. Li and Song (2020) and Fan, et al. (2021) pointed out that rural tourism and farmhouse entertainment, resulting in a large increase in the construction of new houses, destroyed the original structure of rural settlements, which is consistent with the results of this study.

4.3. *Rural community development advice*

The public sector needs to regulate the rural household registration population, and allocate suitable rural residential areas according to the needs of the rural population. Enhance land regulation through restrictive policies regulating residential land supply (Fan, et al., 2021; Heins, 2004; Li & Song, 2020; Liu, et al., 2014). Looking at the changes in the total population of the four rural communities, the rural population has gradually decreased due to industrialization and urbanization (Liu, et al., 2014). However, the research results show that the construction land is constantly increasing, which contradicts the reduction of the population, and this transformation is also somewhat destructive.

It is very necessary to accurately locate the development types of rural communities (ecological, productive and living community). The development of ecotourism in rural communities can balance ecology and economy, and it has been proved to have positive benefits for forest regeneration, which is an appropriate way to achieve sustainable development (Arif, et al., 2022; Tu & Chen, 2020).

It is necessary to establish legal norms for permanent land policies in rural communities and strengthen law enforcement and supervision by public departments. The permanent land policy of rural communities is legally regulated, and it is necessary to delineate specific areas as permanent farmland, forest land, water area and ecological protection land, and it is forbidden to change the nature of land use and prohibit development and construction. In addition, refine the strategy of permanent farmland, forest land, water area and ecological protection land, and build high-quality land use areas. Permanent farmland conservation policies are the most commonly used land use tool to combat land use conversion. This measure can limit the fragmentation of the land and has certain significance for the maintenance of the ecosystem(Daniels, 1999; Daniels & Bowers, 1997; Eagle, et al., 2015; Li, 2019). For non-permanent land use permits, the zoning classification cannot be changed arbitrarily, and top-down legal management is required. Public and private ownership of land has been proven to be an important issue affecting land use change, and private land has a negative impact on the protection of forests and farmland (Lu & Cheng, 2023; Tu & Chen, 2020). Tu and Chen (2020) pointed out that forest land and slope land should avoid land privatization. Subsidies and land expropriation for private agricultural or forest land are active strategies (Cots-Folch, et al., 2006; Robinson & Brown, 2009; Tu & Chen, 2020). Cots-Folch, et al. (2006) pointed out that the regulatory policy of the European Union, subsidizing up to 50 % of terraces and encouraging such activities, has positive effects on land use transformation. Robinson and Brown (2009) can have positive effects through meaningful siting expropriation. In addition, studies have shown that one of the key factors related to the effectiveness of permanent land policies is the regulation of implementation by the public sector (Alfasi, et al., 2012; Kline, et al., 2014). It is necessary to provide supervision mechanisms for rural communities and higher-level public sector institutions, and conduct supervision and management on a quarterly basis. These suggested measures can provide a reference for the formulation of regulations on the spatial planning system in rural communities in Taiwan.

4.4. *Research limitations*

The limitations of this research stem from the image data. (1) The time of the aerial image drawings of the four rural communities is not uniform, which is limited by cloud cover and public image data. (2) The source of the aerial image drawing is not the same month or season, and the land cover will be slightly different due to the influence of seasonal climate, for example, the influence of seasons on water volume and vegetation. (3) The impact on land cover will be slightly different due to the difference in the age of trees. For example, the trees in the early years, due to artificial planting, present an array layout, so they will be classified as farmland. However, today, as time goes by, the trees grow up and are classified as forest land from remote sensing images. Therefore, there are certain research limitations in the digitalization stage of the four stages of landscape spatial pattern change analysis.

5. Conclusions

From 2001 to 2020, land use change in four different types of rural communities has common ground. (1) From the perspective of land use analysis, the growth of construction land and transportation land in the four communities is a common phenomenon. The growth rate of construction and transportation land matches the type of rural community. (2) From the perspective of land cover types, forest land or farmland in each community is the most important land cover, but each community has its characteristics. (3) From the perspective of land transfer analysis, the mutual conversion and loss of farmland, forest land, and other land use.

This study believes that the driving forces for the changes in the landscape spatial pattern of rural communities mainly come from the policies of the public sector, the spatial planning system, community development activities. (1) Before 2007, living, ecological, and production rural communities focused on hardware development, and the land conversion was relatively large. At this stage, the landscape spatial pattern was in a development stage that tended to be fragmented. (2) By 2013, rural communities were in a transition period from hardware to software. At this stage, the landscape spatial pattern is still in a stage of fragmented development. The landscape fragmentation phenomenon is most obvious in the Gangbian, Shuangtan and Dalian communities, while the Seshui community continues to be fragmented. (3) After 2013, rural communities focused on software development. The landscape spatial pattern in this stage tends to develop slowly and improve.

However, the landscape fragmentation of the living community (Shishui) will be the most significant in 2019.

It is suggested that for the development of rural communities in Taiwan in the future, rural communities need the regulation of the rural registered population by the public sector, and allocate suitable rural residential areas according to the needs of the rural population. Rural communities need an accurate definition of the type of development. Rural communities need to establish legal norms for permanent land policies and strengthen law enforcement and supervision by the public sector.

CRediT authorship contribution statement

Fuer Ning: Conceptualization, Methodology, Software, Writing – original draft, Data curation, Investigation, Software, Validation. **Hui Wang:** Supervision. **Yu-Chen Chien:** Supervision. **Haozhang Pan:** Visualization, Investigation, Software, Validation. **Sheng-Jung Ou:** Methodology, Supervision, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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Appendix A

Table A1.
Table A2.

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