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The Production–Living–Ecological Land Classification System and Its Characteristics in the Hilly Area of Sichuan Province, Southwest China Based on Identification of the Main Functions

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Received: 13 February 2019; Accepted: 12 March 2019; Published: 16 March 2019

Abstract: Production–living–ecological land (PLEL) is one of the research focuses of land planning and regional sustainable development in China. This paper builds a three-level classification system of PLEL based on the identification of the main land use functions (LUFs). Taking 215 typical towns in the hilly area of Sichuan Province, Southwest China as samples, the quantitative, spatial, and functional characteristics and impact factors of PLEL were studied. The results showed that (1) production land holds a dominant role in the hilly area of Sichuan Province, and production land (PL), living land (LL) and ecological land (EL) account for 66.06%, 7.60%, and 26.34% of the area, respectively. The area of agricultural production land is the largest; forestland and rural living land rank second and third. (2) The spatial patterns of PLEL in different regions of hilly area have differences. The proportion of PL gradually decreases from north to south, while the proportion of EL gradually increases from north to south, and the difference in LL is not obvious. The EL is mainly distributed in the upper and middle parts of hills, and the PL and LL are mainly distributed in the foot slopes and valleys. (3) The main functions of PLEL in the hilly area of Sichuan are production and ecology. The production function is mainly for agricultural and forestry products, and the living function is mainly for cultural leisure and residential functions. There are little differences among the ecological sub-functions. (4) There is a strong correlation between PLEL and natural–social–economic factors in the hilly area of Sichuan. Natural conditions such as latitude, relative height, and surface roughness have significant impacts on PL and EL. Social and economic factors such as population density, location and total industrial output value have a significant impact on LL. The results of this study provide valuable implications for the spatial planning and sustainable development in the Sichuan Basin and upstream of the Yangtze River.

Keywords: Production–Living–Ecological Land (PLEL); Land Use Functions (LUFs); impact factor; land classification system; Sichuan Province

1. Introduction

Land is a multi-functional comprehensive system; humankind uses land for a multitude of purposes, obtaining many functions (economic, environmental and social) from any particular form of land use [1]. In recent decades, along with rapid industrialization, urbanization and economic development, dramatic changes in land use have been observed in China. On the other hand, the conflict between population, resources and the environment is becoming more serious, and the competition between various lands is becoming increasingly fierce [2]. For example, wetlands or other ecological land have been destroyed or have even disappeared. The quantity and quality of productive land, such as cultivated land, have been reduced. Living land, such as residential land, has been created in a disordered way, and its layout has been chaotic. That has caused increasingly serious problems in China, such as resource constraints, environmental pollution and ecosystem degradation [3,4]. The report of the Eighteenth National Congress of the Communist Party of China pointed out that China should ensure "the space for production is used intensively and efficiently, that the living space is livable and proper in size, and that the ecological space is unspoiled and beautiful". Optimizing the production–living–ecological space has become one of the core contents of China's ecological civilization and sustainable development strategy. Moreover, it will become the foundation of the spatial planning system [5]. However, the current land use classification published by the Chinese government is based on the economic and social functions of land, with inadequate consideration of ecological processes and ecosystem services [6–8]. Therefore, it is necessary to establish a land classification system based on the multifunction of land use in China.

Land use functions (LUFs) are defined as the private and public goods and services provided by the different land uses, summarizing the most relevant economic, environmental and societal aspects of a region [9–12]. The LUF concept, with its roots in agriculture, ecosystem goods, and services and landscape functions, has been integrated into nine categories in the SENSOR (Sustainability Impact Assessment: Tools for environmental, social and economic effects of multifunctional land use in European regions) project. According to LUFs, land use systems can be categorized into three classes: productive land, living land, and ecological land; namely, production–living–ecological land (PLEL) [13,14]. Production land (PL) is related to industrial structure and refers to the main function of providing industrial products, agricultural products and service products. Living land (LL) is related to carrying and maintaining human settlements and refers to the main functions of providing human living, consumption, leisure and entertainment. Ecological land (EL) is related to the natural ecosystem and refers to the main function of providing ecological products and services, playing an important role in regulating, maintaining and ensuring regional ecological security [5]. The three classes of PLEL are closely related, mutually transformed, and constantly exchange material and energy. The EL is the foundation, PL is the driving force, and LL is the link of PLEL [4,13].

In recent years, PLEL has attracted widespread attention from governors, planners and scholars for promoting sustainable economic and social development. Based on the system theory of the element–structure–function analysis framework, land use types are classified into single or compound types of PLEL through qualitative and quantitative identification of LUFs, and then the multi-scale and multi-level classification system of PLEL are established [15,16]. The research scale can be divided into three levels; the first is large-scale, and Zhang et al. [17] and Liu et al. [14] have constructed the national classification system of PLEL in China and revealed the spatial pattern of PLEL. The second is the medium scale, mainly taking provincial-level regions, large river basins and urban agglomerations as research objects, covering Hubei Province [2], Chongqing province [18], Jiangsu province [19,20], Yangtze River basin [21,22], Bailongjiang River basin [23], Fujian Delta urban agglomeration [3], Jianghuai urban agglomeration [24], and Wuhan urban circle [25] in China. The third is the small scale; the main research objects are county-level regions in China's main ecological regions [26–32]. Li et al. [33] and Xi et al. [34] have carried out the classification system and quantitative identification of PLEL at the rural level. Nevertheless, the concept and classification system of PLEL have not yet been unified. Many classification systems are too conceptual and theoretical, and there are still defects in linking them with the current land use classification system. Meanwhile, there are generally fewer research samples at the county scale or below, and the representation of the research results needs to be further confirmed. Besides, there is still a lack of PLEL research in Sichuan Basin. This study has built a three-level classification system of PLEL, based on the main functions identification of LUFs (production, living and ecological functions). Taking 215 typical towns in the hilly area of Sichuan Province, Southwest China as samples, the quantitative, spatial, and functional characteristics and impact factors of PLEL were studied. The results of this study provide valuable information for the optimal allocation of PLEL and sustainable development in the Sichuan Basin and upstream of the Yangtze River.

2. Materials and Methods

2.1. Study Area

The hilly area of Sichuan Province is located in the upper reaches of the Yangtze River in Southwest China (102°47′–107°28′, 28°10′–31°53′) with an area of about 84,000 km^2 and including 70 counties (Figure 1). The terrain is high in the north and low in the south, with an elevation of 250–600 m. The region belongs to the subtropical humid monsoon climate zone. The annual sunshine hours are 1200–1600 h, the annual average temperature is 16–18 °C, and the annual rainfall is 900–1200 mm. In 2015, the GDP of the hilly area of the Province was 1428.6 billion yuan, the population was 42.2 million, and the grain output was 21.3 million tons, accounting for 46.5%, 51.5% and 61.8% of the totals in Sichuan Province, respectively. It is an important region for environmental protection and economic development in the upper reaches of Yangtze River. However, due to the fragmentation of the natural landscape, low forest coverage and low efficiency of agricultural production and land use, serious problems such as soil degradation, environmental pollution, resource depletion, and decline of biodiversity have arisen. This region suffers the most serious soil erosion in the Sichuan Basin and the upper and middle reaches of the Yangtze River [35,36].

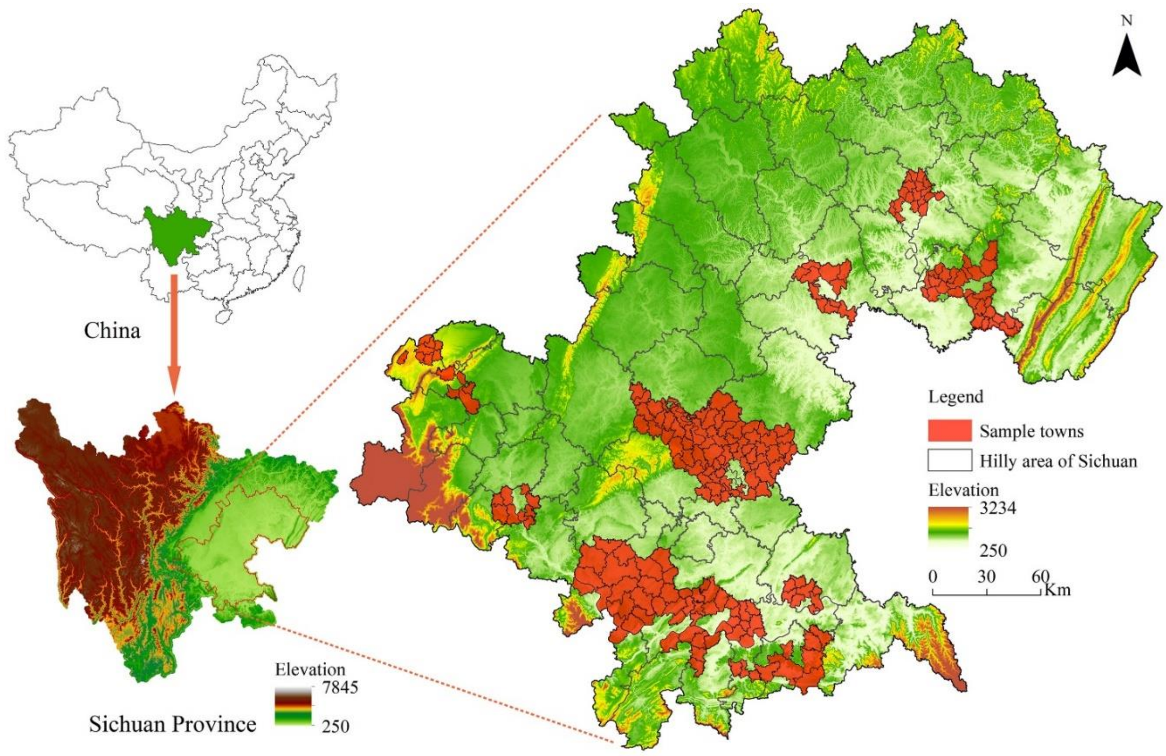

Figure 1. The study area of hilly area in Sichuan Province, Southwest China.

2.2. Data Sources

Land use data were acquired from Pleiades-1 and Google Earth satellite images in 2015. Image enhancement of remote sensing images was processed by Erdas Imagine software. Referring to China's Classification Criteria of Land Use Status (GB/T 21010–2007), a vector map (1:10,000 scale) of land use was produced through field investigation and the visual interpretation of the remote sensing image using ArcGIS. DEM (Digital Elevation Model) data was collected from the advanced spaceborne thermal emission and reflection radiometer global digital elevation model provided by NASA for free (ASTERGDEM) [37]. The socioeconomic data in this study was collected from the Statistical Yearbook of Sichuan Province (2015) and the Statistical Yearbook of various counties in Sichuan Province, using SPSS 24 to analyze the data.

2.3. Classification and Identification of Production–Living–Ecological Functions (PLEF)

2.3.1. Classification System of PLEF

Land is a multi–functional comprehensive system; the production, living and ecological functions are interrelated and transformed, and different land use patterns divide the LUFs into primary and secondary functions [9,10]. PLEL is a dynamic process of land resource quantity and spatial reallocation [5]. Therefore, identifying the main functions of different land use patterns is the key to the classification of PLEL. This paper established a LUF classification system from the perspective of production–living–ecological functions (PLEF). Production function (PF) is the function of providing various products and services for society with land as the carrier, including two sub-functions: agricultural & forestry production and industrial & mineral production. Living function (LF) is the function of land to provide space carrying and spiritual security for human survival and life, including three sub-functions: residence, traffic, and culture & recreation. Ecological function (EF) refers to the function of the ecosystem to provide ecological products to human beings and maintain ecological balance; refer to Costanza et al. [38], MA (Millennium Ecosystem Assessment) [39] and Xie et al. [40]. Ecosystem service classification methods include seven sub-functions: gas regulation, climate regulation, waste treatment, water regulation, soil formation and retention, nutrient cycling, and biodiversity. Based on the previous studies [3,18] and assessment of ecologists in Sichuan Province, land use (GB/T 21010-2007) is divided into four grades according to the capability and integrity values of PLEF (maximum 5 points, medium 3 points, minimum 1 point, function deficiency 0 points); the assessment of land use types is shown in Table 1.

2.3.2. Main Functions Identification of PLEF

To identify the main functions of PLEF for land use types, the evaluation values of sub–functions need to be comprehensively evaluated and ranked. The cluster analysis method can analyze multi–factors and their similarities to study regional differences. It is an important method to quantitatively study the classification of geographical things and the problem of geographical zoning [41]. The hierarchical clustering method was used to identify the main PLEF of land use types in this study, which is a commonly used method at present. The formula is as shown in Equation (1):

$$D_{ij} = \sqrt{\frac{1}{n}\sum_{k=1}^{n}\left(x_{ik} - x_{jk}\right)^2} \quad (1)$$

where D_{ij} is the similarity coefficient of PLEF between land use type (i) and land use type (j), x_{ik} is the functional score value of PLEF for land use type (i), x_{jk} is the functional score value of PLEF for land use type (j), and n is the number of land use types.

Table 1. Classification system and assessment of production–living–ecological function (PLEF) for land use types.

Land Use Type	Ecological Function							Production Function		Living Function		
	Gas Regulation	Climate Regulation	Waste Treatment	Water Regulation	Soil Formation & Retention	Nutrient Cycling	Biodiversity	Agricultural & Forestry Production	Industrial & Mineral Production	Residence	Traffic	Culture & Recreation
Paddy field	3	1	1	3	1	1	1	5	0	0	0	3
Irrigated land	1	1	1	3	1	1	1	5	0	0	0	1
Arid land	1	1	1	1	1	1	1	5	0	0	0	1
Orchard	1	3	1	1	3	1	1	5	0	0	0	3
Tea garden	3	3	1	1	3	1	1	5	0	0	0	3
Other gardens	1	3	1	1	1	1	1	5	0	0	0	1
Forest land	5	5	3	5	5	1	5	3	0	0	0	3
Shrub forest	3	5	3	5	3	1	3	1	0	0	0	1
Other forest lands	5	5	3	3	3	1	3	1	0	0	0	3
Natural grassland	3	3	1	3	1	1	3	1	0	0	0	1
Artificial grassland	3	3	1	3	1	1	1	1	0	0	0	1
Other grasslands	1	3	1	3	1	1	3	0	0	0	0	1
Industrial land	0	0	0	0	0	0	0	0	5	0	0	0
Mining land	0	0	0	0	0	0	0	0	5	0	0	0
Storage land	0	0	0	0	0	0	0	0	5	0	0	0
Urban residential land	0	0	0	0	0	0	0	0	3	5	3	3
Rural residential land	0	0	0	0	0	0	0	0	0	5	0	1
Sightseeing facility land	3	5	3	5	3	1	3	0	0	0	0	3
Railway land	0	0	0	0	0	0	0	0	0	0	5	0
Highway land	0	0	0	0	0	0	0	0	0	0	5	1
Rural road	0	0	0	0	0	0	0	0	0	0	5	1
Port land	0	0	0	0	0	0	0	0	5	0	3	0
Rivers	3	3	5	5	1	1	3	1	0	0	1	3
Lakes	1	3	5	5	3	1	5	1	0	0	0	3
Reservoir	1	3	3	5	3	1	3	1	0	0	0	1
Pond	1	1	3	5	3	1	1	1	0	0	0	1
Inland beach	1	3	1	3	5	3	5	1	0	0	0	1
Ditches	1	1	3	5	1	1	0	0	0	0	0	1
Hydraulic Construction land	0	0	0	0	0	0	0	0	5	0	0	0
Idle land	1	1	3	1	5	3	5	0	0	0	0	0
Agricultural facility land	0	0	0	0	0	0	0	5	0	0	0	1
Saline land	0	0	1	1	5	3	5	0	0	0	0	0
Marshland	3	3	5	5	3	1	5	0	0	0	0	3
Sandy land	0	0	1	1	5	3	3	0	0	0	0	0
Bare land	0	0	1	1	3	1	5	0	0	0	0	0
Urban	0	0	0	0	0	0	0	0	3	5	5	5
Towns	0	0	0	0	0	0	0	0	1	5	3	3
Villages	0	0	0	0	0	0	0	0	0	5	1	1
Sightseeing and special land	3	5	3	5	3	1	3	0	0	0	0	3

2.4. Characteristics of Production–Living–Ecological Land (PLEL)

2.4.1. Calculation of Landscape Metrics

Land spatial pattern has typical spatial heterogeneity, which is a mosaic of patches of different land use types. Landscape pattern analysis based on landscape geometric characteristics can effectively reflect the spatial pattern of land use [42]. Landscape metrics are larger generalizations of landscape pattern information and quantitatively reflect the composition of landscape structure and spatial allocation characteristics. Since this study's objective was to estimate the spatial characteristics of the different sample towns as a whole, the metrics are computed at the class level. For this purpose, we choose nine metrics to describe the spatial pattern of PLEL, including total class area (CA), number of patches (NP), patch density (PD), largest patch index (LPI), edge density (ED), patch area mean (AREA_MN), interspersion juxtaposition index (IJI), landscape division Index (DIVISION) and aggregation index (AI). The calculation formula and meaning of metrics can be found in the references [43]. Considering that Fragstats software works on raster data, we use ArcGIS software to convert land use vector data into raster images. Land use vector data are coded according to nine types of PLEL Class2 and grid cell size is 10 × 10 m according to town level research scale. Fragstats software calculates the landscape metrics of PLEL Class1 and Class2. We use Microsoft Excel software to analyze the landscape metrics calculation results.

2.4.2. Analysis of Landform Elements

Topography and landform are the most fundamental factors to form the structure and function of hills and various ecological phenomena and processes, and they have a significant impact on the intensity and mode of land use [44]. Therefore, analyzing the distribution of landform elements is helpful to understand the regularity of the regional PLEL spatial pattern and has practical significance for the optimization of the PLEL pattern in hilly areas of Sichuan Province. Geomorphons method can extract landform elements accurately, which maps landform elements by recognizing the morphology of each cell of interest in a DEM that is defined according to its relative altitudes within the neighboring window of the interest cell [45]. According to the concept and method of Geomorphons, 10 landform elements are extracted from DEM by GRASS GIS 7 software, which are: flat, peak, ridge, shoulder, spur, slope, hollow, footslope, valley, and pit. Considering the actual situation of hilly areas in Sichuan Province, the results of Geomorphons analysis are merged into five types: summit, ridge, slope, valley, and flat.

2.4.3. Functional Index Model of PLEL

PLEF is the concentrated expression of multi-functional land use characteristics, reflecting the ability of a land system to meet human production, living and ecological activities. Quantitative evaluation of PLEF plays an important role in the analysis of regional PLEL heterogeneity and spatial pattern optimization. Based on the results of the classification and identification of PLEF, a functional index model of PLEL is constructed to analyze the spatial heterogeneity and pattern of PLEF in the hilly area of Sichuan Province. The calculation process includes: first, the total function index and sub-function index of each land use type were calculated by multiplying the evaluation score of PLEF (Table 1) and weight. The weight of PLEF was assigned according to the equality of each PLEF and sub-function [1]: gas regulation, climate regulation, waste treatment, water regulation, soil formation & retention, nutrient cycling, and biodiversity were 0.048; agricultural & forestry production and industrial & mineral production were 0.167; residence, traffic and culture & recreation were 0.111. Second, the function index of land use type is multiplied by area index (The area index is to eliminate the absolute quantity difference of land use type area), and the function index and sub–function index of PLEF in the study area are calculated. Meanwhile, according to the classification system of PLEL, land use types are converted into types of PLEL, and then the functional index and sub–function index of each PLEL types are calculated. The functional index value is calculated by the following formula:

$$F_i = \sum_{k=1}^{n} \frac{A_{ij}}{A_i} \times f_j \tag{2}$$

$$f_j = \sum_{k=1}^{m} I_m \times S_m \tag{3}$$

where F_i is the functional index of PLEL in area (i); A_{ij} is the area of land use type (j), A_i is the total land area of area (i), f_j is the functional index of land use type (j), I_m is the weight of PLEF in item (m) of land use type (j), and S_m is the score (Table 1) of PLEF in item (m) of land use type (j).

2.5. Pearson Correlation Coefficient

The spatial distribution pattern of PLEL was the result of a combination of natural environment and human activities. The Pearson correlation coefficient is used to present the linear relationship between two random variables. It has been widely used in correlation analysis of land use impact factors [2]. In this paper, 12 natural and socio-economic factors (Longitude, Latitude, Altitude, Relative altitude, Surface roughness, Location condition, Population density, Government revenue, Crop sown area, Gross industrial output, Total retail sales of social Consumer goods, and Urban built-up area) were selected to correlate with the proportion of PL, LL and EL. The formula is as shown in Equation (4):

$$r_{xy} = \frac{\sum(x_i - \overline{x})\sum(y_i - \overline{y})}{\sqrt{((x_i - \overline{x}))^2}\sqrt{((y_i - \overline{y}))^2}} \tag{4}$$

where $\overline{x}$ denotes the mean of x. $\overline{y}$ denotes the mean of y. The coefficient r_{xy} ranges from -1 to 1. The sign of the correlation coefficient is positive if the variables are directly related and otherwise negative if they are inversely related. If $r_{xy} = 0$, then x and y are deemed to be uncorrelated. The closer the value of $|r_{xy}|$ is to 1, the stronger the measures are close to a linear relationship.

3. Results and Analysis

3.1. Classification System of Production–Living–Ecological Land (PLEL)

The results of hierarchical clustering analysis show that (Figure 2) when the distance between groups is about 14, land use types can be divided into four categories, which correspond to ecological function, agricultural & forestry production function, industrial & mineral production function, and living function. After proper merging, the identification results of PLEF for land use types were obtained (Table 2).

Table 2. Identification result of PLEF for land use types.

Main Function of PLEF	Clustering Group	Land Use Type
Ecological function	1	Forest land, Shrub forest, Other forest lands, Natural grassland, Artificial grassland, Other grasslands, Sightseeing facility land, Rivers, Lakes, Reservoir, Pond, Inland beach, Ditches, Idle land, Saline land, Marshland, Sandy land, Bare land, Sightseeing and special land.
Production function	2	Paddy field, Irrigated land, Arid land, Orchard, Tea garden, Other gardens, Agricultural facility land.
	3	Industrial land, Mining land, Storage land, Port land, Hydraulic Construction land.
Living function	4	Urban residential land, Rural residential land, Railway land, Highway land, Rural road, Urban, towns, villages.

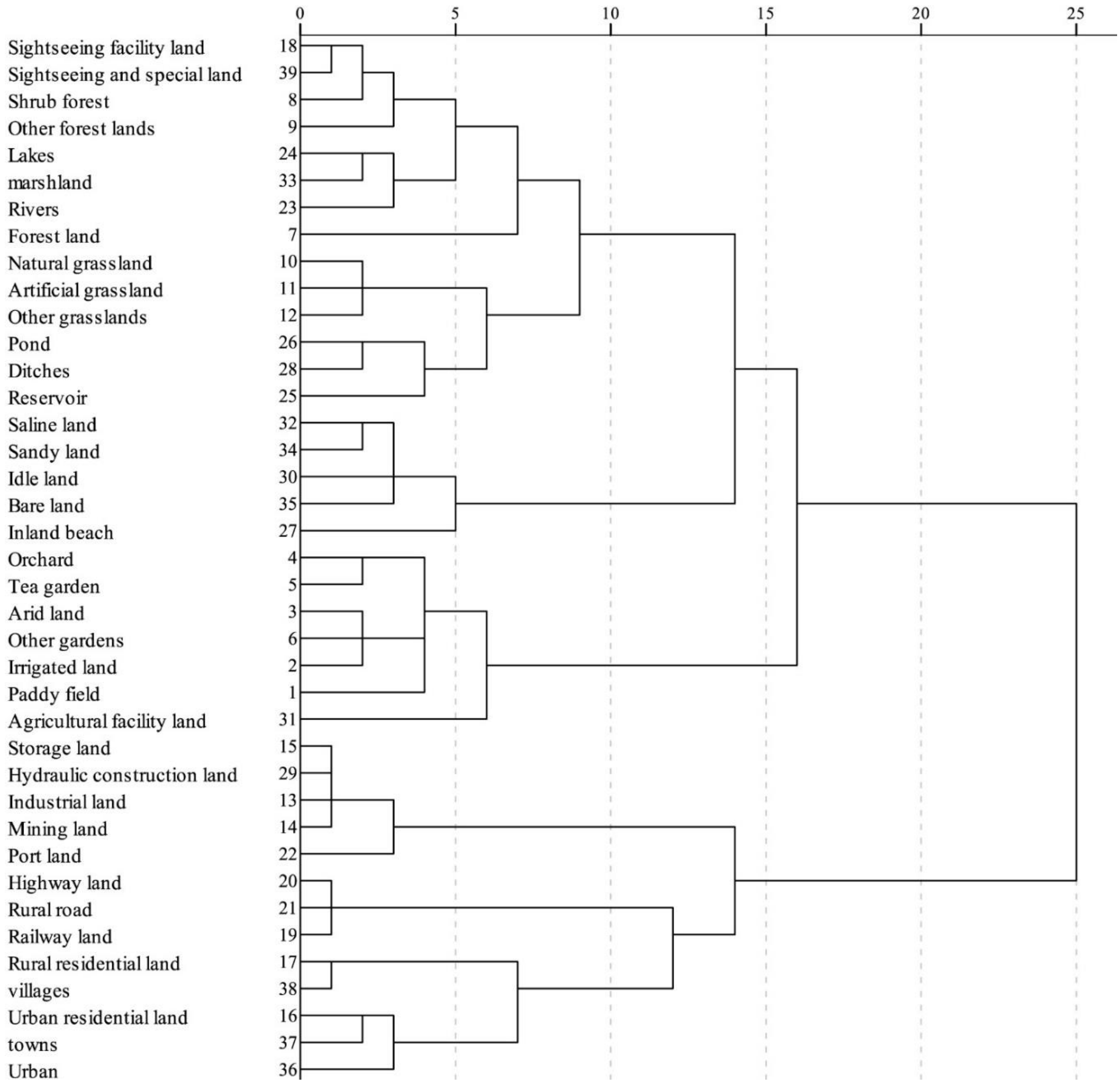

Figure 2. Result of hierarchical clustering analysis of PLEF.

Based on the main function identification of PLEF, the classification system of PLEL has been established. This classification system reclassifies land use types into PLEL types; especially, ecological land was classified according to the national standards of Wetland Classification (GB/T 24708-2009) and the Classification and Codes for Forestry Resources–Forest Types (GB/T 14721-2010). The naming principle of PLEL was based on a natural ecosystem or land landscape patterns, which ensures that the PLEL types were easy to understand in concept and better to identify in space. The classification system of PLEL consists of a three-level classification (Table 3). The first level class includes productive land (PL), living land (LL) and ecological land (EL), reflecting the main PLEF attributes of land use. The second level class includes nine types; the ecological land is divided into four types according to ecosystem types and related standards, the production land is divided into two types according to industrial attributes, and the living land is divided into three types according to social attributes. The third level class subdivides the second level class into 21 types.

Table 3. Classification system of PLEL in the hilly area of Sichuan.

PLEL Class 1	PLEL Class 2	PLEL Class 3	Land Use Type
Ecological land	Wetland	Riverine Wetland Lacustrine Wetland Marshy Wetland Human-made Wetland	Rivers, Inland beach Lakes Marshland Reservoir, Pond, Ditches
	Forest land	Arbor forest land Shrub forest land Other forest land	Forest land Shrub forest Other forest lands
	Grassland	Natural grassland Artificial grassland	Natural grassland, Other grasslands Artificial grassland
	Other ecological land	Sightseeing and special land Idle land Saline land Sandy land Bare land	Sightseeing and special land Idle land Saline land Sandy land Bare land
Production land	Agricultural production land	Paddy field Arid land Orchard	Paddy field Irrigated land, Arid land, Agricultural facility land Orchard, Tea garden, Other gardens
	Industrial production land	Industrial & Mineral land	Industrial land, Mining land, Storage land, Port land, Hydraulic Construction land
Living land	Urban living land	Urban land	Urban, towns, Urban residential land
	Rural living land	Rural residence land	Villages, Rural residential land
	Traffic land	Traffic land	Railway land, Highway land, Rural road

3.2. Analysis of PLEL Distribution Characteristics

3.2.1. Quantitative Structure Characteristics of PLEL

PL, LL and EL accounted for 66.06%, 7.60% and 26.34%, respectively, of the total area of the study area in hilly areas of Sichuan Province (Table 4). The proportion of PLEL was quite different, and production space occupied a dominant position. From the PLEL Class 2, the proportion of agricultural production land was the highest, accounting for 65.86% of the study area. Forest land and rural living land ranked second and third, while industrial productive land accounts for the smallest proportion. This structure shows that the rural hilly areas in Sichuan are still in the stage of socioeconomic development of traditional agriculture, and the production function, especially the agricultural production function, is an important direction of land use at present. Moreover, there is a strong negative correlation between EL and PL (Figure 3); the quantitative structure of the above two types of PLEL may have some internal relationship. The dynamic change of the structure of PLEL may be mainly caused by the mutual transformation between EL and PL.

Table 4. The quantitative structures of PLEL in the hilly area of Sichuan. Unit: hm^2, %.

PLEL Class 1	Area	Ratio	PLEL Class 2	Area	Ratio
Productive land	694,604.39	66.06	Agricultural productive land Industrial productive land	692,493.15 2111.24	65.86 0.20
Living land	79,879.88	7.60	Urban living land Rural living land Traffic land	6775.65 67,622.65 5481.58	0.64 6.43 0.52
Ecological land	276,911.81	26.34	Wetland Forest land Grassland Other ecological land	42,711.88 226,065.15 4453.38 3681.40	4.06 21.50 0.42 0.35

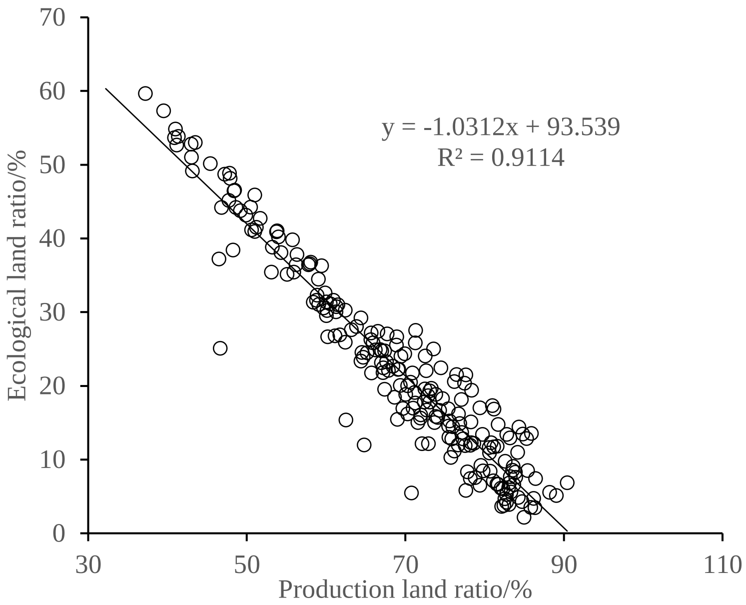

Figure 3. Scatter plot of the relation between ecological land and production land (*n* = 215).

3.2.2. Space Distribution Characteristics of PLEL

There are regional differences in the spatial distribution of PLEL in hilly areas of Sichuan Province (Figure 4). The proportion of PL gradually decreases from north to south, while the proportion of EL gradually increases from north to south, and the regional difference of LL is not obvious. Meanwhile, the imbalance of PLEL in hilly areas of central Sichuan is the highest, followed by the hilly areas of northeast Sichuan. Further analysis shows that agricultural production land and forest land are the main reasons for regional differences.

Fragstats software was used to analyze the landscape pattern of 215 sample towns in hilly areas, and nine indexes of class level landscape pattern were calculated (Table 5). Total class area (CA), largest patch index (LPI), edge density (ED), patch area mean (AREA_MN), and the interspersion juxtaposition index (IJI) of PL are significantly higher than LL and EL, and the number of patches (NP) and patch density (PD) of LL were the highest. The results show that the patches of PL are larger, the shape is more complex, and the distribution is more centralized, while the number of LL is higher, the area is smaller, and the distribution is very fragmented. The spatial distribution pattern of EL is between PL and LL.

Table 5. Statistics of class level landscape metrics of PLEL in the hilly area of Sichuan.

Landscape Pattern Indexes	Production Land	Living Land	Ecological Land
Total class area (CA hm^2)	1649.89	148.75	362.93
Number of patches (NP n)	115.20	492.15	210.06
Patch density (PD n/100 hm^2)	1.84	9.47	3.84
Largest patch index (LPI %)	18.92	0.44	1.63
Edge density (ED m/hm^2)	84.89	30.79	36.61
Patch area mean (AREA_MN hm^2)	59.93	5.39	1.93
Interspersion juxtaposition index (IJI %)	53.19	40.43	35.89
Landscape division Index (DIVISION %)	0.89	1.00	1.00
Aggregation index (AI %)	98.98	97.47	98.20

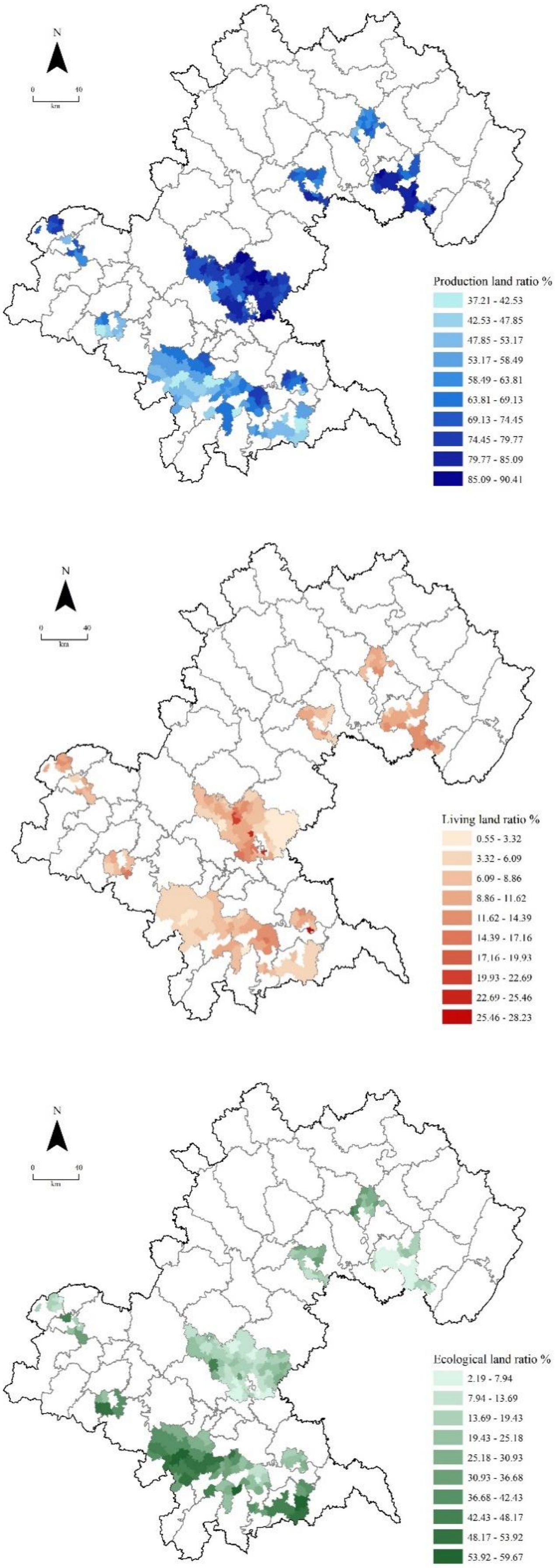

Figure 4. The spatial distribution of PLEL in the hilly area of Sichuan.

According to the concept and method of Geomorphons [41], 10 landform elements are extracted from DEM by GRASS GIS 7 software. Considering the actual situation of hilly areas in Sichuan Province, the above landform elements were merged into five types: summit, ridge, slope, valley, and flat (Table 6). The results show that the proportion of EL such as forest land and grassland in the upper and middle hills is higher than PL and LL, while wetlands are mainly distributed in flats and valleys. Paddy fields and arid land are mainly distributed in the middle and lower parts of hills, of which paddy fields have the highest proportion in valleys; arid land is more distributed in the upper and middle parts of flat hills such as ridges; and garden land is relatively concentrated in slopes. LL is mainly distributed in slopes, valleys and flats, of which rural residence land is distributed more in flats and urban land is distributed more widely in the upper part of hills. The distribution of PL and LL in the upper and middle parts of hilly areas in Sichuan is more than that in the flat areas, which will have adverse effects on soil erosion control and ecological environment construction and become the key direction of optimizing the spatial distribution pattern of PLEL.

Table 6. Statistics of topographic position distribution in the hilly area of Sichuan. Unit: %.

PLEL Class 3	Summit	Ridge	Slope	Valley	Flat
Riverine wetland	0.3	10.6	28.4	57.6	3.1
Lacustrine wetland	3.7	22.7	25.3	40.6	7.7
Marshy wetland	3.2	29.8	36.1	24.7	6.1
Human-made wetland	4.9	24.8	36.2	27.8	6.4
Arbor forest land	3.6	26.0	38.9	22.6	8.9
Shrub forest land	5.2	23.9	35.2	26.8	8.9
Other forest land	0.0	0.0	0.0	100.0	0.0
Natural grassland	3.5	26.1	23.1	38.3	9.0
Artificial grassland	0.0	0.0	40.7	48.5	10.7
Sightseeing and special land	4.8	23.6	36.5	25.3	9.7
Paddy field	2.0	24.4	28.7	38.9	5.9
Arid land	2.6	27.7	28.8	34.2	6.7
Orchard	3.4	28.9	33.8	26.5	7.4
Industrial & Mineral land	3.4	19.9	41.0	27.4	8.2
Urban land	0.7	26.5	37.5	32.5	2.8
Rural residence land	5.9	22.0	31.7	29.4	10.9
Traffic land	1.7	27.9	30.4	34.7	5.3
Total	2.8	26.4	30.9	33.3	6.6

3.2.3. Functional Characteristics of PLEL

The results of the functional index calculation show that production and ecology are the main functions of PLEF in the Sichuan hilly area, among which agricultural & forestry production is the main PF, residence and culture & recreation are the main LFs, while the sub-functional index of EF shows little difference (Table 7). Further analysis shows that the six types of PLEL with the highest functional index are arid land, paddy field, arbor forest land, orchard, rural residence land and riverine wetland. Among them, the highest EF index of PLEL is for arbor forest land, paddy field and arid land. The highest PF index is for arid land, paddy field and arbor forest land. The highest LF index is for paddy field, rural residence land and arbor forest land. The above data analysis indicates that the PLEF in Sichuan hilly areas is dominated by arid land, paddy field, arbor forest land, and rural residence land.

3.3. Analysis of PLEL Impact Factors

The spatial distribution pattern of PLEL was the result of a combination of natural environment and human activities. In this paper, 12 natural and socio-economic factors were selected to correlate with the proportion of PL, LL and EL, and Pearson correlation coefficients were calculated (Table 8). The results show that longitude and latitude were significantly positively correlated with PL, significantly negatively correlated with EL, and weakly positively correlated with LL, which was consistent with the spatial distribution of PLEL. The relative altitude and surface roughness were significantly correlated with PLEL: positively correlated with EL and negatively correlated with PL. The industrial and agricultural production in the Sichuan hilly area was greatly affected by the topography, mainly distributed in the relatively flat area, while the ecological land was mainly distributed in the middle and high hilly area with complex topography. From the socio-economic factors, the location condition was the linear distance between the geometric center of town and the nearest city, which is significantly negatively correlated with the LL, indicating that the rural settlements in hilly areas tend to concentrate around the city. Population density was significantly positively correlated with LL and PL and negatively correlated with EL, indicating that human activities had a significant impact on PLEL patterns. Crop-sown area was positively correlated with PL and negatively correlated with LL and EL, but the correlation coefficient was not high, indicating that the level of agricultural development only had a certain impact on PLEL. The gross industrial output, total retail sales of social consumer goods, and urban built-up area had a positive impact on LL.

Table 7. Statistics of functions indexes of PLEL in the hilly area of Sichuan.

Production–Living–Ecological Functions		Total	Production Land	Living Land	Ecological Land
Production function	Agricultural & Forestry production	142.0	122.8		19.2
	Industrial & Mineral production	0.5	0.5		
	Subtotal	142.5	123.3		19.2
Living function	Residence	17.3		17.3	
	Traffic	1.4		1.4	
	Culture & Recreation	48.9	31.7	2.5	14.7
	Subtotal	67.6	31.7	21.3	14.7
Ecological function	Gas regulation	22.7	12.8		9.9
	Climate regulation	18.4	8.2		10.2
	Waste treatment	14.2	7.0		7.2
	Water regulation	23.5	12.5		10.9
	Soil formation & retention	17.9	8.1		9.7
	Nutrient cycling	9.4	7.0		2.4
	Biodiversity	17.2	7.0		10.2
	Subtotal	123.2	62.7		60.5
	Total	333.3	217.7	21.3	94.3

Table 8. Correlation analysis on influencing factors of PLEL in the hilly area of Sichuan.

Impact Factors		PL Ratio	LL Ratio	EL Ratio
Natural factors	Longitude	0.276 **	0.168 *	−0.306 **
	Latitude	0.411 **	0.127	−0.419 **
	Altitude	−0.043	−0.159 *	0.088
	Relative altitude	−0.542 **	−0.149 *	0.546 **
	Surface roughness	−0.496 **	−0.225 **	0.526 **
Socio-economic factors	Location condition	−0.004	−0.401 **	0.124
	Population density	0.276 **	0.517 **	−0.410 **
	Government revenue	−0.104	0.103	0.065
	Crop sown area	0.252 **	−0.252 **	−0.157 *
	Gross industrial output	−0.171 *	0.381 **	0.044
	Total retail sales of social Consumer goods	−0.167 *	0.207 **	0.093
	Urban built-up area	−0.071	0.258 **	−0.011

Note: ** Significant correlation at the significant level of 0.01 and * Significant correlation at the significant level of 0.05.

4. Conclusions

Based on the PLEF classification and evaluation established by LUFs, this paper established a three-level PLEL classification system. Taking more than 200 typical townships as samples, the quantitative structure, spatial pattern, functional level characteristics, and impact of socio-economic factors of PLEL in the hilly areas of Sichuan Province, China were revealed by using RS, GIS and landscape ecological methods and techniques. Some conclusions can be drawn, as follows:

(1) PLEL in hilly areas of Sichuan Province shows a quantitative structure dominated by production space. PL, LL and EL account for 66.06%, 7.60% and 26.34% of the total area of the study area, respectively. The proportion of agricultural production land is the highest, forestland and rural living land are the second and third, while industrial production land is the smallest;
(2) There are regional differences in the spatial distribution of PLEL in hilly areas of Sichuan Province. The proportion of PL gradually decreases from north to south, the proportion of EL gradually increases from north to south, while the regional difference of LL is not obvious. Meanwhile, the imbalance of PLEL in hilly areas of central Sichuan is the highest, followed by the hilly areas of northeast Sichuan. The analysis results of the landscape pattern show that the patches of PL are larger, the shape is more complex and the distribution is more centralized, while the number of LL is higher, the area is smaller, and the distribution is very fragmented. The spatial distribution pattern of EL is between PL and LL. EL such as forest land and grassland were mainly distributed in the upper and middle hills. PL such as paddy field and arid land are mainly distributed in the middle and lower parts of hills, of which the paddy field has the highest proportion in valleys. LL is mainly distributed in slopes, valleys and flats, of which rural residence land is distributed more in flats;
(3) Production and ecology are the main functions of PLEF in Sichuan hilly areas, among which agricultural & forestry production is the main PF, residence and culture & recreation are the main LF, while the sub-functional index of EF has little difference. PLEF in Sichuan hilly areas is dominated by arid land, paddy field, arbor forest land, and rural residence land;
(4) The distribution pattern of PLEL in hilly areas of Sichuan Province is greatly impacted by natural conditions and socio-economic factors. Five natural conditions mainly affect PL and EL, among which latitude, relative altitude and surface roughness had the greatest impact. Population density is the most important socio-economic factor affecting PLEL. Location condition, gross industrial output, total retail sales of social consumer goods, and urban built-up area have a greater impact on LL.

Scientific analysis of PLEL patterns and trends is key to realizing the optimization and coordinated development of land spatial allocation in hilly areas of Sichuan Province. This paper only preliminarily studied the PLEL classification system, attribute characteristics and impact factors in hilly areas of Sichuan Province. Further research into PLEL scale effects, dynamic evolution, ecological–economic value evaluation, and optimal allocation is needed.

Author Contributions: G.L., X.G. and L.D. conceived and designed the experiment. H.Z. and N.F. collected the data. G.L. and P.H. analyzed the data. W.Z. and O.D. helped the language correction; G.L. wrote the paper.

Funding: This research received no external funding.

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

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