Heliyon 10 (2024) e33481

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Analysis of the spatial differentiation and driving force of arable land abandonment and non-grain in the hilly mountainous areas of Gannan

Hao Yuan, Yonglin Chen *, Jianping Lin, Yunping Zhang, Chenhui Zhu

School of Geography and Environmental Engineering, Gannan Normal University, Ganzhou, 341000, China

ARTICLE INFO

Keywords:
Arable land abandonment
Arable land non-grain
Driving mechanisms
Hilly mountainous areas
Geodetector

ABSTRACT

Food security has a bearing on national development and people's livelihoods and is an important guarantee of social stability for national development. The problems of arable land abandonment and non-grain are becoming more and more serious, and national food security is difficult to guarantee, which will seriously hinder the forward development of China's society and economy. Taking Ruijin City of Jiangxi Province as an example, this study calculated the abandonment level and non-grain level of arable land in Ruijin City respectively from two aspects, and explored the spatial differentiation law of farmland abandonment and non-grain level in the hilly and mountainous areas of southern Jiangxi Province by using spatial autocorrelation and cold and hot spot analysis methods, and the causes of arable land abandonment and non-grain spatial differentiation in the hilly mountainous areas of Gannan were revealed by the methods of Geodetector factor detection and interaction detection. Conclusions of the study: (1) Ruijin City, the abandoned area was 1216.73 hm^2, the abandonment rate of each village ranged from 0.01 % to 50.62 %, and the comprehensive abandonment rate was 4.90 %; the area of non-grain was 2937.27 hm^2, and the rate of non-grain of each village ranged from 0.01 % to 100.00 %, and the comprehensive non-grain rate was 11.83 %. The area of non-grain was 2937.27 hm^2, and the rate of non-grain in each village ranged from 0.01 % to 100.00 %, and the comprehensive rate of non-grain was 11.83 %. (2) The phenomenon of abandonment of arable land and non-grain in Gannan hilly and mountainous areas has a certain clustering and driving effect in space. Globally, the phenomena of arable land abandonment and non-grain in Ruijin City are positively correlated, with the global Moran's I of arable land abandonment rate being 0.05, and the global Moran's I of arable land non-grain being 0.73. (3) Whether or not arable land in the hilly mountainous areas of Gannan is abandoned is affected by the combination of socioeconomics, natural resources, farming conditions, and economic location, with elevation, the degree of arable land contiguity, and population density being the dominant factors. The interaction of elevation, degree of concentration and contiguity, field regularity, and per capita arable land area increased the spatial variability of arable land abandonment in the hilly mountainous areas of Gannan. Whether the phenomenon of non-grain occurs or not is affected by socio-economic conditions, farming conditions and economic location, of which the proportion of paddy fields, land transfer price, arable land area, and urban-rural gradient are the dominant factors. The proportion of paddy land, the price of land transfer, the area of arable land, and the urban-rural gradient interact with each other, and the tendency of arable land to be planted with non-grain crops is more serious.

* Corresponding author.
E-mail address: 0200026@gnnu.edu.cn (Y. Chen).

https://doi.org/10.1016/j.heliyon.2024.e33481
Received 28 November 2023; Received in revised form 11 June 2024; Accepted 21 June 2024
Available online 24 June 2024
2405-8440/

1. Introductory

Arable land is the foundation of farmers, food is the cornerstone of national stability, and the negative impact of the global epidemic on food security is still spreading today [1,2],extreme weather [3,4] geopolitical conflict [5–7]. It has also brought some shock to the international food market. at the same time, with the accelerated process of urbanization and industrialization in the country, the influx of rural laborers into the cities and the increase in the non-farming population, the proportion of arable land devoted to non-grain crops has been rising year by year [8],the problems of abandonment of arable land and the non-grain of arable land in China are becoming increasingly serious, and food security is under great threat. In 2022, the Central Government particularly emphasized the need to guarantee food security and implement "long teeth" arable land protection measures, China as a large agricultural country, under a variety of unstable factors, "to serve the Chinese people their own rice bowls", guaranteeing national food security is particularly important [9–11]!

From the perspective of research direction, the previous research of scholars on the arable land issue is mainly a single phenomenon of arable land abandonment or arable land non-grain phenomenon, for the phenomenon of arable land abandonment, Guo and other scholars analyzed from the perspective of the spatial and temporal pattern of arable land abandonment [12], Qiu and other scholars through the study of the impacts of urban expansion and low productivity on arable land abandonment, found that megacities and first-tier cities have higher levels of abandonment [13].While earlier studies on arable land abandonment have focused on the extraction of information on abandonment [14,15] and the causes of abandonment. There is no uniform standard for arable land abandonment in the academic community, but it can be roughly summarized as "the behavior of farmers who fail to make rational use of arable land resources under the influence of multiple conditions, such as natural conditions and socio-economic conditions". In response to the phenomenon of non-grain arable land, Guan and other scholars regulate and optimize the layout of non-grain arable land from the aspects of ecological services, ecological sensitivity, etc., which alleviates the contradiction between agricultural development and environmental protection to a certain extent [16], and Zhu and other scholars predict the future non-grain arable land patches by constructing land use simulation models [17]. In terms of research methods, scholars have mostly used spatial autocorrelation analysis [18] to analyze the spatial and temporal distribution of the phenomena of arable land abandonment and arable land non-grain in the context of arable land abandonment and arable land non-grain. At the same time, scholars mostly use Tobit model [19], probit model [20], random forest model [21], spatial error model [22], multiple linear regression method [23], logistic regression [24] and other ways to explore the influencing factors of two kinds of arable land phenomena. From the perspective of research scale, the problems of arable land abandonment and non-grain have been involved at the provincial scale [25] and city and county scales [26]. Most of the existing studies have focused on the administrative unit scale, and most of them are macro studies and qualitative studies. China's topography is diverse, and the southern part of China is mostly low mountainous and hilly, the terrain of low hills is complex, and arable land is distributed according to the topography, with fragmented plots, poor commuting and irrigation difficulties, and low farming efficiency, which makes the abandonment of arable land and the phenomenon of non-grain more likely to occur [27–29].

This study selects Ruijin City in Jiangxi Province as the study area, which is in the Gannan hilly mountainous area in the south of Jiangxi Province, and the Gannan hilly mountainous area is the typical representative of the southern hilly mountainous area, so the study area has a certain degree of representativeness. Based on the existing research, this study simultaneously launched a comparative analysis of the two problems of arable land abandonment and arable land non-grain in Ruijin City, identifying the types of arable land abandonment and non-grain, of which the non-grain problem is mainly the non-grain of the type of transformation of cultivation structure. The problem of non-grain mainly studies the non-grain of arable land planting structure transformation, simultaneously studies its spatial distribution pattern and potential driving factors, searches for the dominant factors of the two types of arable land problems with a geographic detector, and explores the interaction relationship between them separately, and makes a comparative analysis of the problems of arable land abandonment and arable land non-grain. The comparative analysis of the potential influencing factors of the phenomenon of arable land abandonment and arable land non-grain makes up for the shortcomings of the existing studies to a certain extent and has certain scientific validity and feasibility. The results of this study are intended to serve as a reference for government departments in formulating countermeasures and avoiding a blind "one-size-fits-all" approach to the issue of arable land.

2. Overview of the study area and data sources

2.1. Overview of the study area

Ruijin City is in the hilly mountainous area of Gannan in the southern part of Jiangxi Province, near the southern section of the Wuyi Mountains, and in the upstream area of Gongshui, the eastern source of the Gan River. Located at the junction of Jiangxi, Fujian, and Guangdong provinces, it is an important transit point between the central and western provinces and the southeastern coast (Fig. 1). The terrain is varied, and it is one of the four major basins in Jiangxi with a large basin area. The climate belongs to the transition zone between the climate of central and southern China, and it is a subtropical monsoon humid climate with four distinct seasons, favorable temperatures, sufficient rainfall, and sunshine. According to the data of the Third National Land Survey of Ruijin City in 2019, the total area of Ruijin City is 2442.03 km^2, of which the arable land area is 248.39 km^2.The terrain is dominated by hills, which account for 80.35 percent of the total land area, and the mountainous area is 243.89 km^2, which accounts for 9.96 percent of the total land area, and it has the characteristics of the typical hilly and mountainous areas. The region mainly grows grain crops such as rice and sweet potato, and its grain crop yield is high, which is one of the main agricultural industries. In addition to grain crops, the

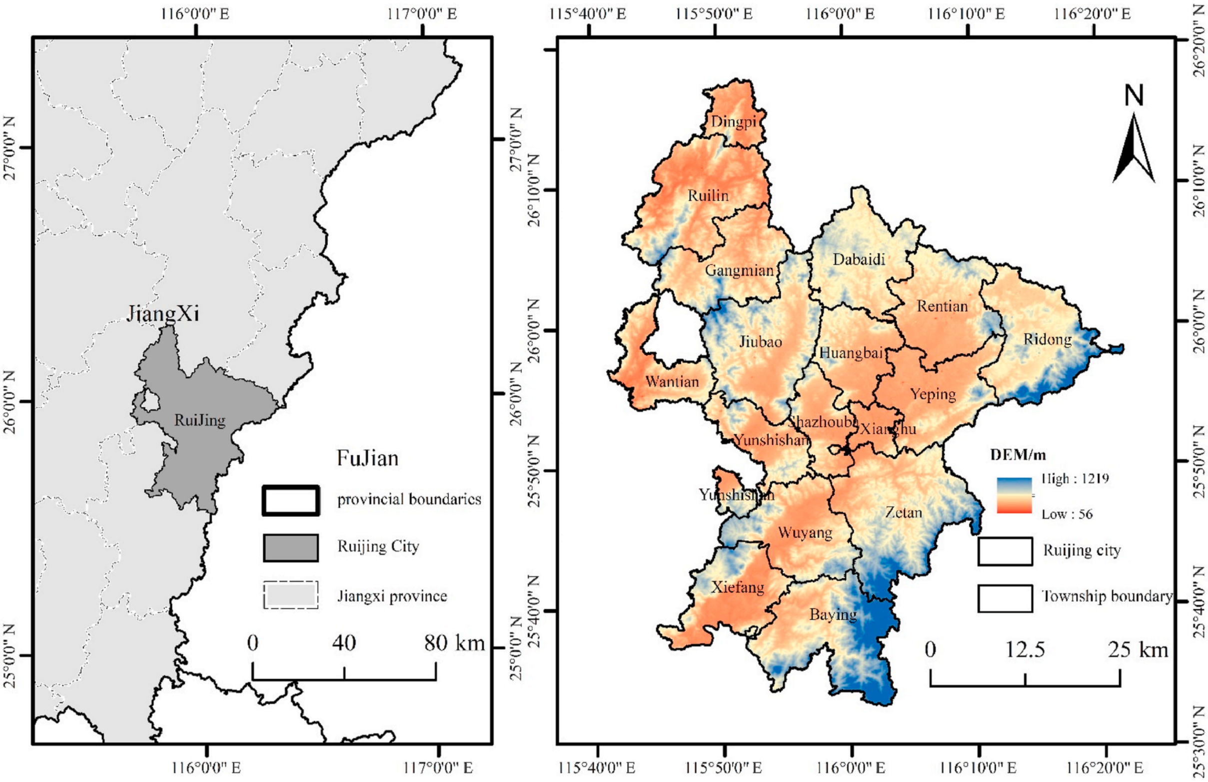

Fig. 1. Schematic map of the geographical location of Ruijin City.

region also has navel orange, oil tea and greenhouse vegetable cultivation, which is an advantageous industry in agriculture. According to statistics, the sown area of grain in Ruijin City has slightly decreased from 2018 to 2019, and the corresponding grain production has also decreased.

2.2. Data sources

The data sources of this study are as follows: (1) the results of the Third National Land Survey (hereinafter referred to as the "Third Survey"), digital elevation model (DEM) data, and administrative boundaries were obtained from the Natural Resources Department of Ruijin City; (2) the compensation standards for land expropriation in Ruijin City were obtained from the Ruijin City 2020 National Economic and Social Development Bulletin; (3) Ruijin City socio-economic status data were obtained from the 2020 Ruijin Yearbook.

3. Research methodology

3.1. Arable land non-grain rate

Current research suggests that arable non-grain can be categorized into food-producing non-grain and non-grain-producing non-grain [30,31]. However, there is still no authoritative data published on arable land cultivated with non-grain crops in the province, so the issue of non-grain on arable land studied in this paper mainly refers to the cultivation of food non-grain, where food crops mainly include rice, sweet potatoes and pulses, and non-grain crops include sugar beets, peanuts, vegetables, and melons. Food crops include rice, sweet potatoes, and legumes, while non-grain crops include sugar beets, peanuts, vegetables, and melons. Therefore, the non-grain rate (R) in this paper refers to the ratio of the area of non-grain crops to the total area of arable land [32]. Formula is expressed as (1).

$$Ri = \frac{Ni}{Gi} \times 100\% \tag{1}$$

Style: R_i is the non-grain rate in village i (%); Ni is the area of non-grain crops in village i (km^2); Gi is the total area of arable land in village i (km^2).

3.2. Arable land abandonment rate

The ratio of the area of abandoned arable land to the total area of arable land within the village area of Ruijin City was used to express the abandonment rate of arable land in the village area [33]. Formula is expressed as (2).

$$Pi = \frac{Ai}{Si} \times 100\% \quad (2)$$

Style: P_i is the rate of abandonment of arable land in village i (%); Ai is the area of abandoned arable land in village i (km^2); S_i is the total area of arable land in village i (km^2).

3.3. Spatial autocorrelation model

Spatial autocorrelation analysis includes global and local spatial autocorrelation, and in this study, we mainly measured the degree of spatial clustering of non-grain rate and abandonment rate and the spatial location of the clustering center [33]. In this paper, Global Moran's I is used to investigate the spatial clustering or discrete distribution properties of non-grain rate and abandonment rate. The Global Moran's I index generally takes a value between [−1,1], a positive value of the index indicates a clustered distribution, a negative value of the index indicates a discrete distribution, and a value of 0 indicates no correlation and a random distribution. Formula is expressed as (3).

$$I = \frac{m}{P_0} \times \frac{\sum_{i=1}^{m}\sum_{j=1}^{m} Wij(z_{i-}\bar{z})(z_{j-}\bar{z})}{\sum_{i=1}^{n}(z_{i-}\bar{z})2} \quad (3)$$

Style: $P0 = \sum_{i=1}^{m}\sum_{j=1}^{m} Wij$,m is the total number of study units in the study area, where and are the values of the abandonment or non-grain levels in regions i and j. $\bar{z}$ is the mean of the observations, and W_{ij} is the spatial weight.

3.4. Cold and hot spot analysis

By using hot and cold spot analyses, it is possible to identify where spatial agglomerations of high-value and low-value elements occur [34]. Hot spots are areas of high value aggregation at the abandonment, or non-grain level, and cold spots are areas of low value aggregation. The formula for analyzing hot and cold spots is expressed as (4).

$$G_i^* = \frac{\sum_{j=1}^{n} Cijkj}{\sum_{j=1}^{n} ki} \quad (4)$$

Style: G_i^* denotes the z-score situation. $z > 0$ and the larger, the higher the value the more concentrated the clustering; $z < 0$ and the smaller, the more concentrated the clustering of lower values.

3.5. Geodetector

Geodetector is a statistical method for detecting spatial divergence as well as revealing the driving factors behind it [35]. In this study, we propose to use two methods: driver detection and interaction detection. Driver detection can be used to analyze the explanatory power of drivers on the spatial differentiation of arable land abandonment and arable land non-grain. The formulae for detecting the non-grain driver of arable land abandonment and arable land are expressed as (5).

$$q = 1 - \frac{1}{N\sigma^2}\sum_{i=1} N_i {\sigma_i}^2 \quad (5)$$

where i is the classification or partition of a variable in space. N is the total number of arable land patches, N_i is the number of arable land patches under the classification of. σ 2and σ i2, these are the variance at the non-grain level for arable land in the whole area, and

Table 1
Interaction types of driving factors.

Basis for judgment	The type of interaction
$q(x_1 \cap x_2) < \mathrm{Min}(q(x_1), q(x_2))$	nonlinear attenuation
$\mathrm{Min}(q(x_1), q(x_2)) < q(x_1 \cap x_2) < \mathrm{Max}(q(x_1), q(x_2))$	Single-factor nonlinear attenuation
$q(x_1 \cap x_2) > \mathrm{Max}(q(x_1), q(x_2))$, $(x_1 \cap x_2) < q(x_1) + q(x_2)$	two-factor enhancement
$q(x_1 \cap x_2) = q(x_1) + q(x_2)$	stand alone
$q(x_1 \cap x_2) > q(x_1) + q(x_2)$	nonlinear enhancement

the variance at the non-grain level for arable land under a certain classification. Interaction detection reflects the interaction between the drivers [36], which can be categorized into five types: non-linearly enhanced, non-linearly attenuated, one-factor non-linearly attenuated, two-factor enhanced, and independent (Table 1).

3.6. Driving force indicator construction

In this paper, we take the proportion of arable land non-grain and arable land abandonment area under the grading of each driving force indicator as the dependent variable Y, and construct a total of 16 driving force indicator systems under the four dimensions of socio-economic conditions, natural resource conditions, cultivation conditions, and economic location, among which the degree of field neatness, the degree of contiguity of arable land and so on reflect the background differences of the arable land in terms of production capacity, suitable mechanization, and infrastructural support, etc., the elevation, the degree of topography undulation, and so on reflect the natural conditions of the arable land, the urban and rural gradients reflect the spatial relationship between the supply and demand for the non-grain products, and the socio-economic conditions reflect the strength of the demand table of the arable land cultivation (Table 2).

4. Results

4.1. Analysis of the current situation of arable land abandonment and arable land non-grain in Ruijin City

Using the "Third Survey" data of Ruijin City, we can calculate the non-grain level of arable land in the area according to formula (1), and the level of abandonment of arable land in the area according to formula (2), and the relevant results are listed in (Table 3). According to the calculation, the total area of non-grain arable land in Ruijin City is 2937.27 hm^2, and the rate of non-grain arable land is 11.83 %. At the same time, the total area of arable land abandonment in Ruijin City is 1216.73 hm^2, and the rate of arable land abandonment is 4.90 percent.

Based on the non-grain rate and the abandonment rate of arable land in administrative villages, it can be observed that there are obvious differences in the spatial distribution of the non-grain level and the abandonment level, and the specific distribution is shown in Fig. 2. The following are the main observations. Results: In the middle and high hilly areas in the north and southeast of Ruijin City, the level of the abandonment rate of the arable land is higher, in which the abandonment rate is more than 9 %. The total amount of

Table 2
The index system of "non-grain conversion" of arable land and the driving force of arable land abandonment.

Dimensions	Drivers	Indicator explanation
Socio-economic conditions	Land area(X_1)	Total land area/km^2 of the village, reflecting the total amount of land resources within the village boundaries
	Arable land area(X_2)	Total area of arable land/hm^2 in the village area, reflecting the abundance of arable land resources in the villages
	Arable land area per capita(X_3)	Ratio of the total area of arable land within the village to the total population of the village (acres/person), reflecting the scarcity of arable land resources per capita
	Percentage of paddy fields(X_4)	Proportion of paddy land area in the village area to the total area of arable land in the village area/percent, reflecting the internal structure of the use of arable land
	Population density(X_5)	Ratio of total population within the village to total land area of the village (people/km^2), reflecting population density
	Land transfer prices(X_6)	Fees paid for the transfer of arable land per unit area within the village area (yuan/mu)
Natural resource conditions	Altitude(X_7)	Grading using DEM data to reflect vertical zonal differentiation in arable land use
	Elevation(X_8)	The slopes are divided into 5 grades: 0–2, 2–6, 6–15, 15–25 and 25° or more, reflecting the ability of arable land to conserve soil and water, and the ease of cultivation.
	Degree of topographic relief(X_9)	Degree of topographic relief in non-flat areas considering relative height differences, depth of terrain cuts, etc.
Farming conditions	Plot regularity(X_{10})	A metric describing the complexity of field geometry, expressed in fractal dimensions: $FRAC = 2\ln(p/4)/\ln a$, P is the perimeter of the plot; a is the area of the plot
	Degree of concentration (X_{11})	In order to eliminate the impact of rural roads, ditches and scattered features, arable land that is not directly connected within 30 m is contiguous, reflecting the degree of concentration of arable land
	Irrigation conditions (X_{12})	Reflecting hydrological conditions of arable land Irrigation and drought resilience
	Road access(X_{13})	Nearest European distance of arable land from various types of roads, such as highways and rural roads, reflecting conditions of farming commuting and transport of agricultural products
Economic location	Urban-rural gradient I (X_{14})	European distance between arable land and the city center, with the geometric center of the "Third Survey" of urban plots in the city center as the center of gravity to establish a buffer zone in the city of Ruijin to form the scope of the strip.
	Urban-rural gradient II (X_{15})	European-style distance between arable land and the county town, with the geometric center of the "Third Survey" city and town plots in XX town, Ruijin City, as the center of mass to establish a buffer zone to form a monocyclic structure
	Urban-rural gradient III (X_{16})	European-style distance between arable land and the township, with the geometric center of the "Third Survey" township plots in Ruijin City township as the center of mass to establish a buffer zone to form a multi-circle structure

Table 3
The level of non-grain and arable land abandonment in Ruijin City.

Arable land non-grain		Abandoned arable land	
Area/hm^2	Percent/%	Area/hm^2	Percent/%
2937.27	11.83	1216.73	4.90

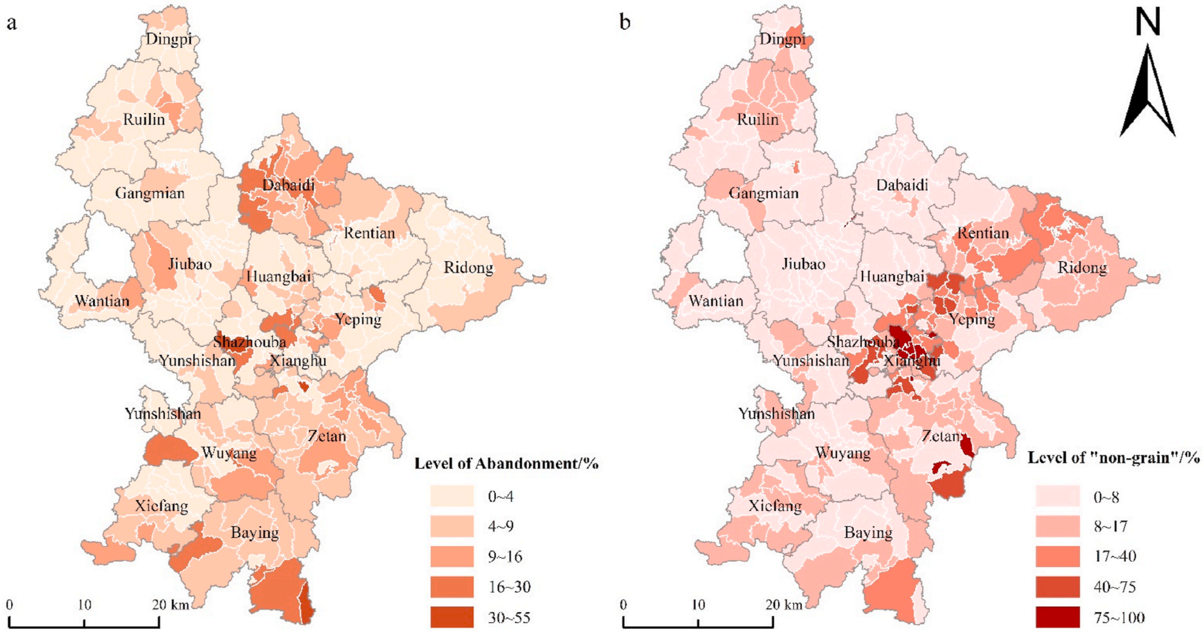

Fig. 2. Level of spatial distribution of arable land abandonment and non-grain.

abandoned arable land in these areas is small at higher elevations, and farmers' considerations of production yields as well as the difficulty of farming have led to an increase in abandoned arable land in the region (Fig. 2a). In the central and northeastern part of Ruijin City, in the lower hillock areas, the non-grain level of arable land is higher, with the non-grain rate exceeding 17 % in most places. This is mainly due to non-grain caused by the restructuring of cultivation. Agricultural activities are gradually shifting from food crops to non-grain crops and other agricultural industries. In general, the distribution of abandoned arable land and non-grain in Ruijin City is closely related to the topography and geographical location. In the central region, non-grain levels are high because of the development of towns and cities and the high demand for non-grain agricultural products; while in the northern and southeastern mountainous regions, the terrain conditions are limited, and farming is less profitable and more difficult, so the level of abandoned arable land is relatively high (Fig. 2b).

4.2. Analyzing the spatial differentiation pattern of non-grain and abandonment of arable land in Ruijin City

4.2.1. Arable land abandonment and non-grain global spatial autocorrelation analyses

By applying GIS technology, this study conducted a global Moran's I analysis (Formula 3) to assess the spatial differentiation characteristics of arable land abandonment and arable land non-grain in Ruijin City. The results of the analyses are shown in the table below (Table 4): the global Moran's I for arable land abandonment was 0.05, while the global Moran's I for arable land non-grain was 0.73. These values reflect the overall spatial distribution characteristics of arable land abandonment and arable land non-grain in Ruijin City.

4.2.2. Analysis of localized spatial hotspots of arable land abandonment and non-grain

In this study, we adopt the administrative village as the unit of analysis and use the spatial hotspot analysis method (Formula 4) to reveal the intensity of the local aggregation of arable land abandonment and non-grain and its spatial distribution. According to the results in Fig. 3, we can see that the hotspots of arable land abandonment are mainly located in Dabaidi Township and Baying Township, which are mainly in the northern and southern areas of Ruijin City. These places are usually located in the high-altitude areas of Ruijin City, where the arable land is at a higher altitude, the agricultural production is diversified, and the income from farming is not high, which leads to the gradual abandonment of the arable land and the abandonment rate is high. Cold spot areas are mainly located in Jiubao Township, Yunshishan Township and Ridong Township in low altitude areas, where arable land is concentrated and continuous, which is conducive to the cultivation and planting of food crops, and the rate of abandonment is low

Table 4
Global spatial autocorrelation test of abandonment and non-grain level.

Categories	Global Moran's I	Z-score	P-value
Abandoned arable land	0.05	1.76	0.08
Arable land non-grain	0.73	25.39	0.00

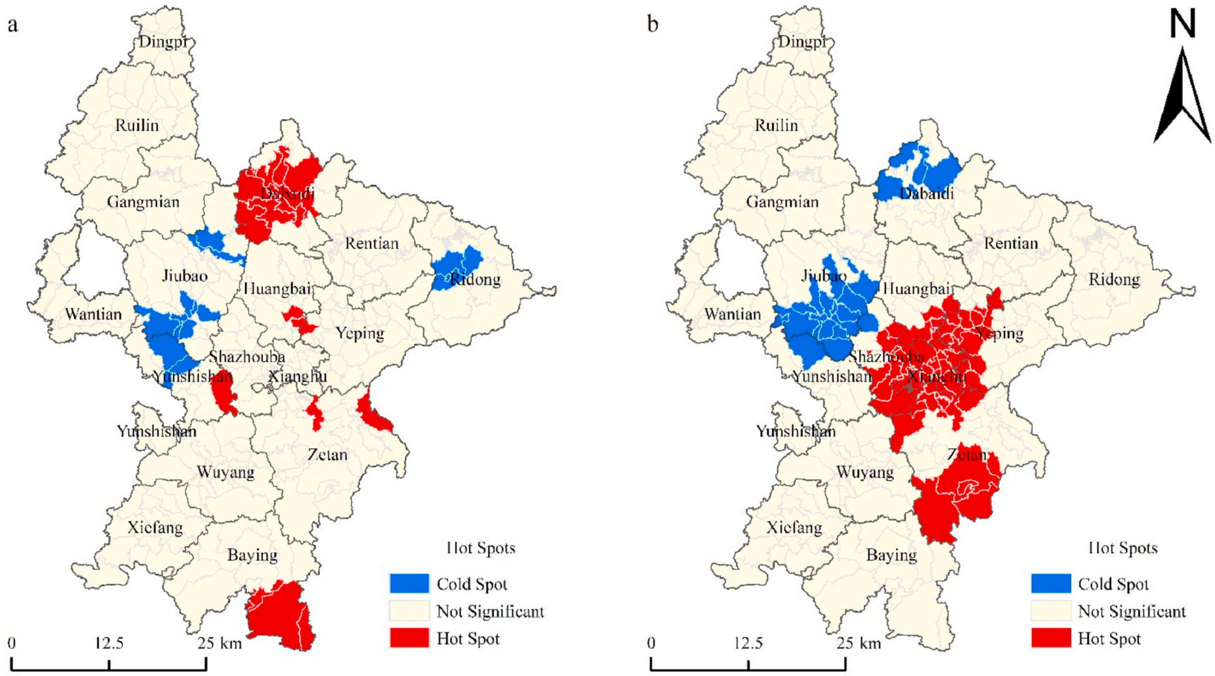

Fig. 3. Types of spatial agglomeration of arable land abandonment and non-grain.

(Fig. 3a). Arable land non-grain hotspots are mainly located in Xianghu Township, Huangbai Township, Shazhouba Township, Yeping Township and Zetan Township, which are mostly located in Ruijin City's central urban area and within the radius of the central urban area. These areas are usually fast urbanizing, close to the market, have concentrated and contiguous land suitable for large-scale operation, and have a high non-grain rate because food crops are less profitable and more non-agricultural crops, such as greenhouse vegetables, are planted to improve their profitability. Arable land non-grain cold spot areas are mainly distributed in Jiubao Township, Dabaidi Township and Yunshishan Township, of which Jiubao Township and Yunshishan Township have large grain yields, good grain income, and the villagers cultivate a large proportion of grain crops, which has a lower non-grain rate (Fig. 3b).

4.3. Arable land abandonment and the detection of non-grain drivers in arable land

The arable land abandonment factor detection (Formula 5) analyzed eight drivers involving four dimensions with p-values passing a 5 % significance test, that is, the driving factors such as arable land area (X_2), per capita arable land area (X_3), population density (X_5), elevation (X_7), slope (X_8), field regularity (X_{10}), centralized contiguity (X_{11}), and urban-rural gradient I (X_{14}) have significant effects on the spatial differentiation of arable land abandonment, but the driving strength of each factor is not of the same magnitude. Comparing the q-values in order, the degree of concentration and contiguity (X_{11}), population density (X_5), arable land area (X_2), per capita arable land area (X_3), and urban-rural gradient I (X_{14}) are the dominant factors, and the corresponding q-values are 0.1792, 0.1654, 0.1266, 0.1043, and 0.0922, respectively (Table 5). This shows that the impact of arable land abandonment level is more obvious under the four dimensions of socio-economic conditions, natural resource conditions, farming conditions and economic location, reflecting that the causes of arable land abandonment are complex, and all aspects have a certain impact on arable land abandonment. Explanation of the driving mechanism of the eight factors that have been tested for significance: when processing the data, through the natural breakpoint method to the arable land area (X_2) for indicator grading, the arable land area is divided into 1 to 5 levels from small to large, the arable land area is positively correlated with the level of arable land abandonment, the larger the arable land area is, the higher the level of arable land abandonment is also higher; through the natural breakpoint method to the per capita arable land area (X_3) to the index graduation, per capita arable land area from small to large is divided into 1 to 5 levels, per capita arable land area and arable land abandonment level is positively correlated, the larger the per capita arable land area, the higher the level of arable land abandonment; through the natural breakpoint method of the population density (X_5) for indicator grading, the

Table 5
Geographic exploration results of arable land abandonment and "non-grain conversion" driving force.

Indicators	Abandoned arable land		Arable land non-grain	
	q-value	Rank	q-value	Rank
X_1	0.0177	13	0.1597[a]	6
X_2	0.1266[a]	3	0.2951[a]	3
X_3	0.1043[a]	4	0.0705[a]	10
X_4	0.0066	15	0.6739[a]	1
X_5	0.1654[a]	2	0.2168[a]	4
X_6	0.0259	10	0.4547[a]	2
X_7	0.0745[a]	6	0.0068	16
X_8	0.0402[a]	7	0.0194	14
X_9	0.0180	12	0.0091	15
X_{10}	0.0306[a]	9	0.0236	11
X_{11}	0.1792[a]	1	0.1307[a]	8
X_{12}	0.0006	16	0.1217[a]	9
X_{13}	0.0176	14	0.0205	12
X_{14}	0.0922[a]	5	0.1668[a]	5
X_{15}	0.0216	11	0.1590[a]	7
X_{16}	0.0338	8	0.0203	13

Note.
[a] indicates significant at the 5 % level.

population density from small to large is divided into 1 to 5 levels, the negative correlation between population density and the level of arable land abandonment, the lower the population density, the higher the level of arable land abandonment; the elevation (X_7) and slope (X_8) are graded by the natural breakpoint method, and the elevation is divided into 1 to 5 levels from low to high, and the slope is divided into 1 to 5 levels from small to large, and the elevation and slope are positively correlated with the level of cropland abandonment, and the higher the elevation and the bigger the slope, the higher the level of cropland abandonment is; the degree of regularity of the field is calculated by the perimeter and area of the cropland patches (X_{10}), and the index of the regularity of the field is near to 1 by the natural breakpoint method. The degree of field regularity is positively correlated with the level of cropland abandonment, the more regular the cropland patch is, the less likely to produce cropland abandonment phenomenon; the degree of centralized contiguity (X_{11}) is graded by the natural breakpoint method, the degree of centralized contiguity is divided into 1 to 5 levels from high to low, the degree of centralized contiguity is negatively correlated with the level of cropland abandonment, the more the degree of centralized contiguity of cropland, the more difficult it is to produce cropland abandonment phenomenon; the degree of centralized contiguity is negatively correlated with the level of cropland abandonment through the natural breakpoint method. The urban-rural gradient I (X_{14}) is graded by the natural breakpoint method, and the distance from the city center is divided into 1 to 5 levels from near to far by the natural breakpoint method, and the urban-rural gradient I (X_{14}) is positively correlated with the level of arable land abandonment, and the closer the distance from the city center is, the higher the level of arable land abandonment will be.

Arable land non-grain factor detection (Formula 5) analyzed 10 drivers across 3 dimensions with p-values passing a 5 % significance test, that is, the driving factors of land area (X_1),arable land area (X_2), per capita arable land area (X_3), proportion of paddy fields (X_4),population density (X_5), price of land transfer (X_6),degree of concentration and contiguity (X_{11}),irrigation conditions (X_{12}), urban/rural gradient I (X_{14}), urban/rural gradient II (X_{15}), have a significant effect on the spatial differentiation of the arable land non-grain, but the intensity of each driver is not the same. Comparing the q-values in order, the proportion of paddy fields (X_4), the price of land transfer (X_6), the area of arable land (X_2), the population density (X_5), and the urban-rural gradient I (X_{14}) are the dominant factors, and the corresponding q-values are 0.6739, 0.4547, 0.2951, 0.2168, and 0.1668, respectively (Table 5). This indicates that the level of non-grain of arable land has a more obvious effect under the two dimensions of socio-economic conditions and economic location, reflecting that the driving force of non-grain of arable land in Ruijin City is socio-economic oriented. Explanation of the driving mechanism of the 10 factors that have been tested for significance: When processing the data, the indicators of land area (X_1), arable land area (X_2), and per capita arable land area (X_3) were graded through the natural breakpoint method, and the land area was divided into 1 to 5 grades from small to large, arable land area was divided into 1 to 5 grades from small to large, per capita arable land area was divided into 1 to 5 grades from small to large, and the land area, arable land area, The land area, arable land area and per capita arable land area are all positively correlated with the level of arable land degrading, the larger the land area, arable land area and per capita arable land area are, the higher the level of arable land degrading; through the natural breakpoint method for the proportion of paddy fields (X_4) to carry out the indicator grading, the proportion of paddy fields is divided into 1 to 5 levels from high to low, the proportion of paddy fields is negatively correlated with the level of arable land degrading, the higher the proportion of paddy fields, the lower the level of arable land degrading; through the natural breakpoint method for the density of the population density (X_5) through the natural breakpoint method for index grading, population density from small to large is divided into 1 to 5 levels, population density and the level of arable land non-grain level is negatively correlated, the smaller the population density, the higher the level of arable land non-grain level; through the natural breakpoint method on the price of land transfer (X_6) for index grading, land transfer price from low to high is divided into 1 to 5 levels, the lower the price of land transfer, the lower the level of arable land non-grain. The lower the land transfer price is, the lower the level of non-grain cultivation of arable land is; through the natural breakpoint method, the indexes of the degree of centralized contiguity (X_{11}) and irrigation conditions (X_{12}) are graded, the degree of centralized contiguity is divided into grades 1 to 5 from high to low, and the distance of irrigation is divided into grades 1 to 5 from near to far, the higher the degree of centralized contiguity is, and the closer the distance of irrigation is, the lower the level of non-grain cultivation of arable land is; through the natural breakpoint method, the indicators of the urban-rural gradient I (X_{14}) and urban-rural gradient II (X_{15}) are graded. The urban-rural gradient I (X_{14}) and the urban-rural gradient II (X_{15}) are classified into grades 1 to 5 in descending order of proximity to the urban center or county center, and the closer the urban center or county center, the easier it is for the arable land to become non-grain.

There were significant differences in the dominant factors of spatial differentiation between arable land abandonment and arable land non-grain. In terms of socio-economic conditions, the q-values of arable land area (X_2), per capita arable land area (X_3), and population density (X_5) at the level of arable land abandonment were larger, reflecting that socio-economic conditions have a stronger explanatory power for whether arable land is abandoned or not, at the level of non-grain of arable land, the q-value of land area (X_1), arable land area (X_2), proportion of paddy land (X_4), population density (X_5), and price of land transfer (X_6) are larger, and firstly, the influence of arable land area (X_2), arable land area per capita (X_3), and population density (X_5) on the degree of abandonment and non-grain of arable land are deeper, with larger arable land area, larger arable land area per capita, and smaller population density. The degree of abandonment and the degree of non-grain are larger in areas with larger arable land area, larger arable land area per capita, and smaller population density, but the relationship between arable land abandonment and arable land non-grain is not as strong as that between arable land abandonment and arable land non-grain. However, the influence of non-grain on the proportion of paddy fields (X_4) and the price of land transfer (X_6) is different, the proportion of paddy fields (X_4) and the price of land transfer (X_6) have a deeper influence on the non-grain of arable land (Fig. 5a,b,5c), while the influence on the non-grain of arable land is weaker. For villages with a lower proportion of paddy fields, the terrain is more favorable for growing other non-agricultural crops, and the type of cultivation is easy to change, so the non-grain is higher; For villages with high land transfer prices, villagers who are not highly dependent on agriculture for their survival tend to go to the city to work and transfer their land to other large agricultural households for agricultural production, and large agricultural households tend to plant high value-added cash crops in order to increase their agricultural returns, and are therefore prone to the phenomenon of non-grain.

In terms of natural resource conditions(Fig. 4a), the two original driving forces, elevation and slope, directly affect the level and distribution of arable land abandonment by changing temperature conditions and restrictive factors such as the ease of cultivation, and the high value areas with high levels of arable land abandonment have higher elevations (X_7) and slopes (X_8), and the proportion of arable land abandonment in villages with better conditions of elevation and slope is on a general trend of decreasing. The effects of elevation (X_7) and slope (X_8) on the non-grain of arable land in Ruijin City did not pass the significance test. From the point of view of farming conditions (Fig. 5d). The degree of field regularity (X_{10}) and the degree of concentration and contiguity (X_{11}) have a greater impact on whether the arable land in Ruijin City is abandoned or not, this is because the degree of field regularity (X_{10}) and the degree of concentration and contiguity (X_{11}) will have an impact on the farming efficiency and willingness to farm, and for the arable land that is more fragmented and distributed, the farming efficiency of the farmers is low, and it is difficult to improve the economic returns, which has a greater impact on the willingness of the farmers to farm. This has a greater impact on farmers' willingness to farm, thus increasing the likelihood of arable land being left fallow. Arable land with a higher level of non-grain has a poorer degree of concentration (X_{11}) and poorer irrigation conditions (X_{12}) (Fig. 4b). Since rice is the main food crop grown on arable land in the southern part of the country, poorly irrigated arable land has a serious impact on rice cultivation, and arable land with a low degree of concentration constrains the efficiency of cultivation, which increases the probability that arable land will produce non-grain.

In order to explore the profound changes in the non-grain and abandonment of arable land on arable land brought about by urbanization, and to characterize the spatial changes in the non-grain and abandonment types under different urban-rural gradient locations, the study is based on the concentric circle theory, and introduces the gradient analysis, which has been widely used in the fields of ecosystem service value and arable land function. The urban/rural gradients I, II and III covering the whole area were formed with the urban, county and town centers as the center of the circle, and the bandwidths of the rings were 7.5, 5 and 1.5 km, respectively, and the levels of non-grain and abandonment were calculated and included in the process of detecting the driving factors

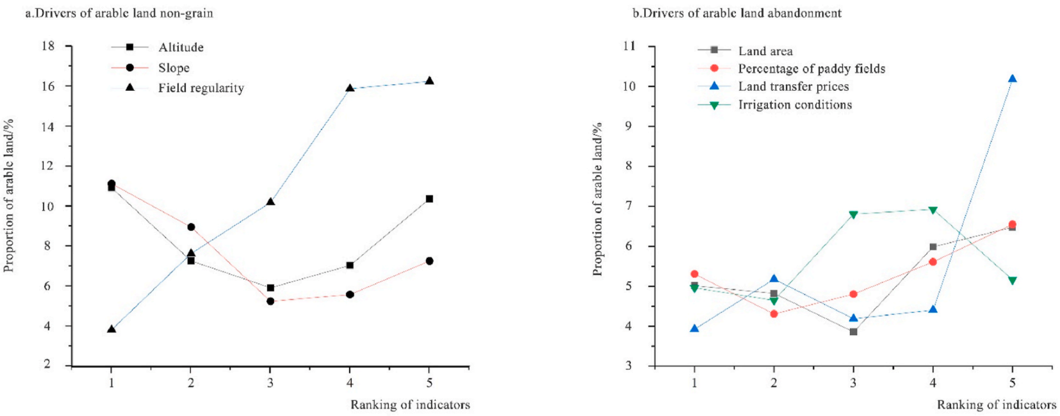

Fig. 4. Arable land abandonment and level of non-grain under different resource endowments.

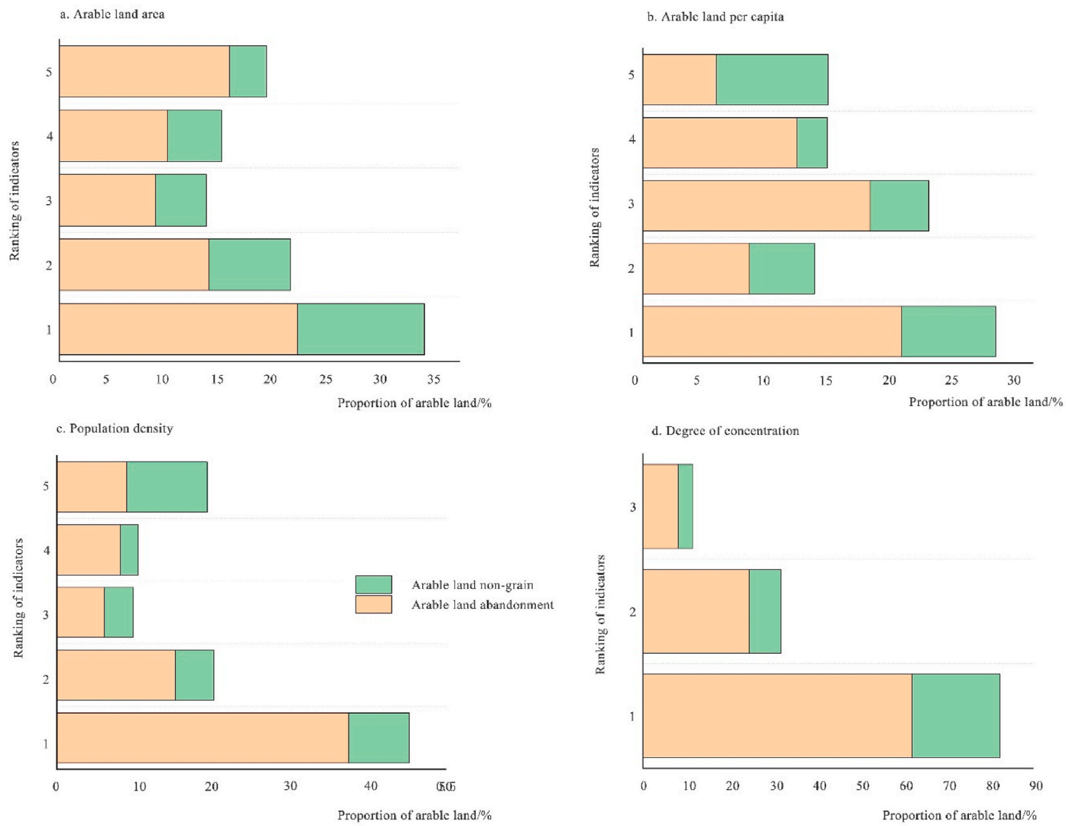

Fig. 5. Proportion of driving factors of arable land abandonment and "non-grain conversion".

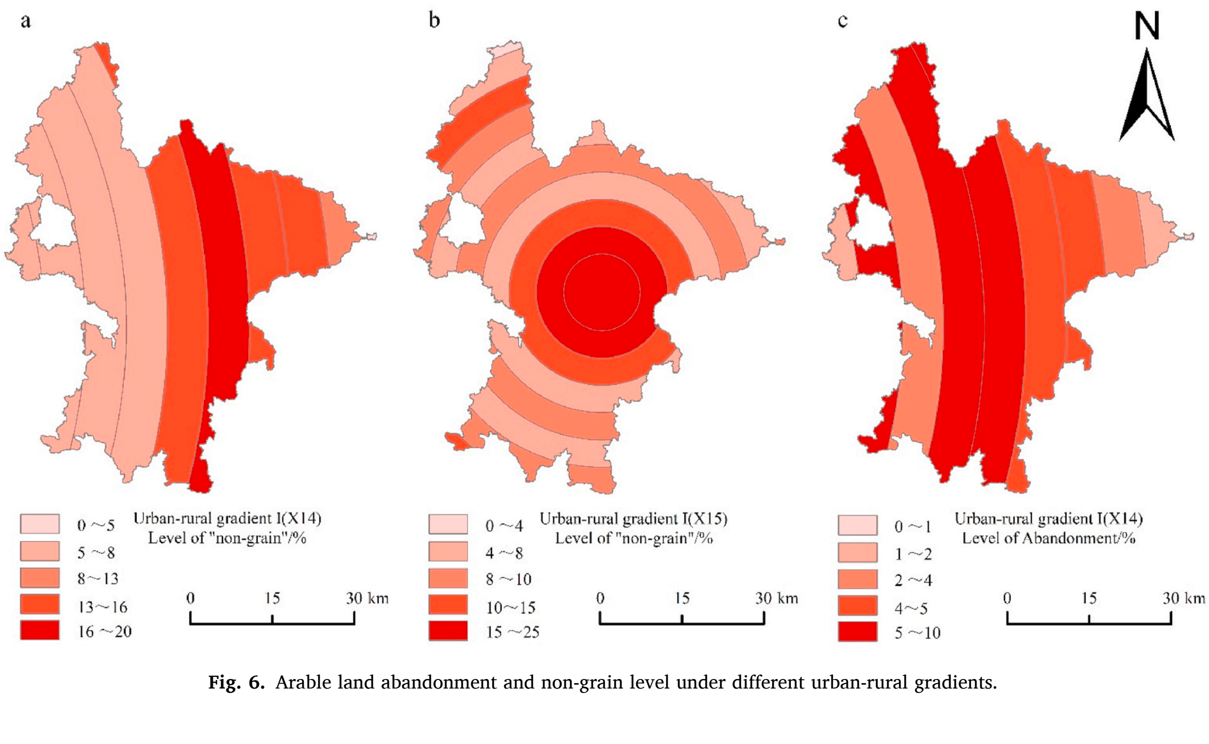

Fig. 6. Arable land abandonment and non-grain level under different urban-rural gradients.

in each ring. The results reflect that the external driving force of arable land location has a certain influence on arable land abandonment and non-grain level, and that the explanatory power of the location advantages of cities, counties and townships gradually decreases, and the municipal location advantages also have a certain influence on arable land abandonment. Fig. 6 shows that because the city center is located in the west direction of Ruijin City(Fig. 6a,b,6c), the combined effect of elevation, traffic and other factors contributes to the significant non-grain of arable land in the township; Gradient analysis shows that the urban-rural gradient II (X_{15}) of the non-grain of arable land generally shows an inverted U-shape distribution differences, the dense population of Ruijin City's central urban area has a greater demand for vegetables, fruits, and other non-grain agricultural products, the 1st to 2nd ring has a higher level of the proportion of non-grain, accompanied by the changes in the circle of the level of non-grain shows a decreasing trend, the 3rd and 4th ring decreasing amplitude is obvious, and the proportion of the occupation of arable land for the development of the fruit and forestry industry in the remote areas is higher. Gradient analysis shows that the urban-rural gradient of arable land abandonment I (X_{14}) shows a general trend of increasing and then decreasing, and the closer to the center of Ganzhou City, the larger the proportion of arable land abandonment; this is due to the higher altitude in the eastern part of Ruijin City, and the radiation effect of the Ganzhou City Economic Circle makes the farmers in the western townships of Ruijin City, driven by economic gains, spontaneously abandon the difficult arable land and go to Ganzhou City to look for work to improve the family's economic income, while the townships in the central part of Ruijin City are more subject to the radiation effect of the Ruijin City, and abandonment of the phenomenon is more obvious, and the townships in the eastern part of Ruijin City are far away from the economic radiation area, and abandonment rate has shown a gradual trend of decreasing.

4.4. Analysis of interaction detection between the factors of arable land abandonment and arable land non-grain

Through the interaction detection analysis of the 16 selected factors, the results show (Table 6) that the influence of any two driving factors after interaction is non-linearly enhanced and two-factor enhanced. Under the interaction of any two drivers, there is greater spatial differentiation of arable land abandonment as well as a more obvious driving effect than that of any single factor. There were 11 two-way enhancements and 109 non-linear enhancements.

The single-factor driving analysis shows that the area of arable land has a greater impact on whether the arable land is abandoned, in which the area of arable land (X_2) has a more obvious increase in q-value after superimposing other driving factors, for example, the area of arable land (X_2) ∩ population density (X_5) has a q-value of 0.258, and the area of arable land (X_2) ∩ elevation (X_7) has a q-value of 0.200. This indicates that Ruijin City wants to reduce the abandonment of land and attract labor flow back to the region to increase

Table 6
Interactive detection results of arable land abandonment.

q-value	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	X_{16}
X_1	0.018															
X_2	0.190	0.127														
X_3	0.167	0.243	0.104													
X_4	0.060	0.208	0.152	0.007												
X_5	0.216	0.258	0.207	0.205	0.165											
X_6	0.112	0.225	0.167	0.085	0.227	0.026										
X_7	0.198	0.200	0.194	0.109	0.201	0.123	0.074									
X_8	0.097	0.166	0.162	0.062	0.190	0.075	0.126	0.040								
X_9	0.077	0.156	0.142	0.039	0.175	0.052	0.089	0.063	0.018							
X_{10}	0.111	0.209	0.149	0.104	0.233	0.098	0.124	0.119	0.059	0.031						
X_{11}	0.304	0.380	0.357	0.288	0.376	0.302	0.280	0.253	0.227	0.228	0.179					
X_{12}	0.058	0.150	0.131	0.017	0.177	0.046	0.113	0.055	0.035	0.084	0.188	0.001				
X_{13}	0.071	0.164	0.142	0.060	0.188	0.078	0.166	0.066	0.043	0.050	0.237	0.050	0.018			
X_{14}	0.136	0.208	0.217	0.188	0.209	0.194	0.264	0.179	0.169	0.152	0.338	0.102	0.139	0.092		
X_{15}	0.090	0.212	0.185	0.070	0.281	0.078	0.202	0.088	0.057	0.089	0.239	0.048	0.093	0.266	0.022	
X_{16}	0.218	0.252	0.237	0.110	0.275	0.105	0.184	0.101	0.064	0.120	0.274	0.050	0.085	0.257	0.126	0.034

Note: The blue fill indicates the single-factor probe result, the yellow fill indicates the nonlinear enhancement in the cross-probing result, and the green fill indicates the cross-probe junction Two-factor enhancement in fruits.

Note: The blue fill indicates the single-factor probe result, the yellow fill indicates the nonlinear enhancement in the cross-probing result, and the green fill indicates the cross-probe junction Two-factor enhancement in fruits.

the area population density under the condition that the total amount of arable land remains unchanged. remains unchanged, it is necessary to attract the labor force to return and increase the population density of the area. In addition, the abandoned land should be adjusted according to local conditions, and the arable land with higher elevation and difficult to cultivate should be returned to forest.

The proportion of paddy fields (X_4) and the degree of terrain undulation (X_9), which did not pass the significance test, still produced a two-factor enhancement effect after superimposing other drivers, such as the proportion of paddy fields (X_4) ∩area of arable land (X_2) with a q-value of 0.208, and the degree of terrain undulation (X_9)∩elevation (X_7) with a q-value of 0.089. This indicates that non-paddy field arable land with a small area is less rewarding for the farmers, and cultivation of arable land with high elevation and high terrain undulation is difficult and prone to fallow phenomenon. Arable land with higher elevation and topographic relief is more difficult to cultivate and prone to abandonment.

Through the interaction detection analysis of the 16 selected factors, the results show (Table 7) that the influence of any two driving factors interacting with each other is non-linearly enhanced and two-factor enhanced. Under the interaction of any two drivers, the non-grain of arable land would show greater spatial differentiation and more obvious driving effect than that of any single factor. There were 42 bifactorial enhancements and 78 nonlinear enhancements.

The single-factor driving analysis shows that the arable land area has a greater influence on whether the arable land is non-grain or not, in which the q value of land area (X_1) increases significantly after superimposing other driving factors, for example, the q value of land area (X_1) ∩ paddy field proportion (X_4) is 0.692, and the q value of land area (X_1) ∩ land transfer price (X_6) is 0.535. land transfer price (X_6) q value is 0.535. This means that the larger the area of land in the region, the smaller the proportion of paddy fields, the higher the transfer price of arable land, the more likely that farmers, driven by economic interests, will plant non-agricultural crops or contract their arable land to large agricultural households to plant cash crops, and the more pronounced is the phenomenon of non-grain on arable land.

Slope (X_8) and terrain relief (X_9), which did not pass the significance test, still produced a two-factor enhancement when stacked with other drivers, e.g., the q-value of slope (X_8) ∩degree of centralized contiguity (X_{11}) was 0.146 and the q-value of terrain relief (X_9) ∩degree of centralized contiguity (X_{11}) was 0.137. This means that in areas where the arable land is more dispersed, with steeper slopes or greater topographic relief, farmers do not have a high willingness to carry out farming, and instead tend to plant cash crops that require less topographic relief and lower slopes to increase family income, thus exacerbating the phenomenon of non-grain arable land in Ruijin City.

Table 7
Interactive detection results of arable land non-grain.

q-value	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	X_{16}
X_1	0.160															
X_2	0.427	0.295														
X_3	0.222	0.443	0.070													
X_4	0.692	0.736	0.708	0.674												
X_5	0.369	0.486	0.310	0.742	0.217											
X_6	0.535	0.553	0.588	0.704	0.671	0.455										
X_7	0.206	0.347	0.095	0.687	0.257	0.491	0.007									
X_8	0.171	0.371	0.114	0.703	0.236	0.473	0.047	0.019								
X_9	0.189	0.361	0.124	0.683	0.247	0.477	0.032	0.027	0.009							
X_{10}	0.206	0.326	0.144	0.723	0.296	0.497	0.066	0.102	0.082	0.024						
X_{11}	0.242	0.491	0.203	0.766	0.337	0.628	0.138	0.146	0.137	0.164	0.131					
X_{12}	0.308	0.345	0.192	0.690	0.346	0.472	0.172	0.185	0.192	0.169	0.306	0.122				
X_{13}	0.170	0.365	0.091	0.678	0.270	0.473	0.036	0.041	0.027	0.084	0.143	0.160	0.021			
X_{14}	0.314	0.438	0.340	0.722	0.282	0.604	0.225	0.256	0.214	0.210	0.285	0.277	0.211	0.167		
X_{15}	0.282	0.515	0.247	0.702	0.301	0.622	0.210	0.196	0.181	0.234	0.232	0.304	0.166	0.273	0.159	
X_{16}	0.245	0.322	0.165	0.704	0.299	0.510	0.060	0.069	0.052	0.090	0.168	0.265	0.056	0.264	0.217	0.020

Note: The blue fill indicates the single-factor probe result, the yellow fill indicates the nonlinear enhancement in the cross-probing result, and the green fill indicates the cross-probe junction Two-factor enhancement in fruits.

5. Discussion

Previous research on arable land mostly focuses on arable land abandonment or arable land non-grain, but this paper, based on the three surveys, uses GIS technology to identify the types of arable land cultivation attributes of "not arable" and "non-grain cultivation", to a certain extent considering the two issues of arable land abandonment and non-grain. Based on the three-survey data, this paper uses GIS technology to identify the types of arable land cultivation attributes of "uncultivated" and "planting non-crops", which, to a certain extent, integrates the two issues of abandonment of arable land and non-grain of arable land. Combining the results of previous research on abandonment and non-grain [37–40],Although the level of arable land abandonment is low compared to the level of arable land non-grain, it does not mean that arable land abandonment is a lower priority for remediation, both of them have the same impact on food security to a certain extent, and will cause some damage to the tillage layer of arable land, both of them need to focus on the management of the arable land with a longer abandonment period. Arable land that has been left fallow for a long period of time is prone to soil fertility loss, and it is difficult to replant the land. The cultivation of other non-agricultural crops on arable land destroys the arable layer, which in the long run is likely to lead to a change in the land use status of arable land and fails to safeguard the 1.8 billion mu of arable land red line, and therefore requires in-depth study.

In terms of the spatial distribution of abandoned arable land, the hotspots of arable land abandonment are mainly located in Dabaidi Township and Baying Township, which are mainly distributed in the northern and southern areas of Ruijin City (Fig. 3).In terms of the degree of abandonment, the abandonment rate of arable land in Ruijin City is 4.90 percent, the abandonment rate of 204 villages ranges from 0.01 percent to 10.00 percent, and that of 44 villages ranges from 10.00 percent to 50.62 percent(Table 8), and its comprehensive abandonment rate level is not considered high. In Ruijin City, the abandonment rate of arable land varies greatly among villages, and the abandonment rate of some villages is much higher than that of other villages. The land abandonment data of Ruijin City is extracted from the data of the Third Land Survey, which can truly and comprehensively respond to the land abandonment situation in Ruijin City, and since the implementation of the important strategies of rural revitalization and village construction, the unique red culture of Ruijin City has attracted a large amount of industrial and commercial capital to seep down, and the non-agricultural employment opportunities and economic income mainly from red tourism and commerce are becoming more and more attractive to the rural labor force, and in the long run, the shortage of labor and the widening income gap between villagers may cause the problem of land abandonment. In the long run, the problem of abandonment of arable land caused by the lack of labor and the widening of the income gap between villagers may become more and more serious.

In terms of the spatial distribution of non-grain arable land, the hotspots of non-grain arable land are mainly located in Xianghu Township, Huangbai Township, Shazhouba Township, Yeping Township and Zetan Township, which are mostly located in the central urban area of Ruijin City as well as within the radiation area of the central urban area (Fig. 3).In terms of the degree of non-grain, the abandonment rate of arable land in Ruijin City is 11.83 percent, the non-grain rate of 156 villages ranges from 0.01 percent to 10.00 percent, the non-grain rate of 103 villages ranges from 10.00 percent to 100.00 percent(Table 8), the overall non-grain rate of Ruijin City is not high, and the non-grain rate among major villages is not high. The overall non-grain rate in Ruijin City is not high, and there are great differences in the non-grain rate among the major villages, with some villages having a non-grain level of up to 10.00 %. In Ruijin City, the combined non-grain rate was not high, and there were great differences in non-grain rates among the major villages, with some villages having a non-grain level of 100.00 percent. The non-grain data of Ruijin City is extracted from the data of the Third Land Survey, which can truly and comprehensively reflect the non-grain status of the arable land in Ruijin City. In the hilly and mountainous areas of Gannan, there is a big difference in arable land resources, and the shape of arable land is not regular, so it is difficult to guarantee the basic income of grain cultivation because of less centralized and continuous management of arable land. Moreover, when developing specialty industries, the contradiction of "grain and economics competing for land" is prominent, and there are a series of contradictions between forestry and fruit industry, greenhouse vegetable cultivation and grain cultivation, and the non-grain level of Ruijin City shows a spatial aggregation effect. Given the typical spatial characteristics of the hilly mountainous areas in Gannan and the differences in the driving factors of non-grain, it is necessary to study the driving factors and spatial differentiation patterns of non-grain on arable land in the hilly mountainous areas of Gannan, to expand and strengthen the understanding of arable land protection and food security in China.

In this study, global Moran's I, local Moran's I and cold hot spot analysis were used to comprehensively analyze the spatial and temporal distribution pattern of farmland abandonment and farmland non-grain. On this basis, the driving factors were analyzed by Geodetector, and the deep relationship between the driving factors and the phenomenon of farmland abandonment and non-grain was explored. Based on previous studies, this study compared the differences in the spatial distribution of farmland abandonment and farmland non-grain phenomenon. At the same time, through a unified driving factor detection, the strength of the influence level of the same factor on farmland abandonment and farmland non-grain phenomenon was studied. The research results are helpful for the government to consider the factors that have strong influence on the two arable land conditions to alleviate the abandonment of arable land and the non-grain phenomenon of arable land by selecting factors that have strong influence on the two arable land conditions

Table 8
Number of villages with different levels of arable land abandonment and non-grain.

	Arable land abandonment level <10.00 %	Arable land abandonment level > 10.00 %	Level of non-grain arable land < 10.00 %	Level of non-grain arable land > 10.00 %
Number of villages	204	44	156	103

when formulating relevant policies and make up for the shortcomings of predecessors in related research. However, there are still some shortcomings in this study. The scale of the study is too small, which can only reflect the arable land status in the hills and mountains of southern Jiangxi Province. In the future research plan, the research area should be expanded, and the research scale should be expanded to the hills and mountains of southern China. In addition, the tillage status of arable land mainly depends on the selection of farmers. When constructing the index system, we should start more from the scale of farmers and comprehensively consider the influence of farmers' selection on the abandonment of arable land and the phenomenon of non-grain of arable land. This research has not taken this aspect into account. Many field investigations, questionnaires, structured interviews, and methods should be used to explore the abandonment of arable land and the non-grain of arable land in depth.

6. Conclusions

(1) Arable land abandonment and non-grain phenomenon are common in Gannan hilly and mountainous areas. In Ruijin City, the area of abandoned arable land is 1216.73 hm^2, with a comprehensive abandonment rate of 4.90 %, and the abandonment rates of 204 villages range from 0.01 % to 10.00 %, and that of 44 villages range from 10.00 % to 50.62 %, of which the higher level of abandonment of the area is Dabaidi Township, Shazhouba Township, Baying Township; Ruijin City, non-grain arable land area of 2937.27 hm^2, the comprehensive non-grain rate of 11.83 %, 204 villages abandonment rate between 0.01 % and 10.00 %, and 44 villages abandonment rate between 10.00 % and 100.00 %, of which the areas with a higher level of non-grain are Xianghu Township, Yeping Township, Rentian Township, Shazhouba Township and Zetan Township.

(2) Arable land abandonment and non-grain phenomena in the hilly mountainous areas of Gannan have certain spatial clustering effects. Globally, the phenomena of arable land abandonment and non-grain in Ruijin City show positive spatial correlation, in which the Moran's I of arable land abandonment is 0.05, and arable land abandonment hotspots are mainly located in arable land abandonment hotspots are mainly located in Dabaidi Township and Bailing Township, which are mainly distributed in the north and south of Ruijin City; and the Moran's I of non-grain is 0.05, and the hotspots are mainly located in Dabaidi Township and Baying Township. Moran's I for non-grain is 0.73, and the hotspots of non-grain arable land are mainly located in Xianghu Township, Huangbai Township, Shazhouba Township, Yeping Township, and Zetan Township, which are mostly located in the central urban area of Ruijin City as well as within the radiation area of the central urban area. They are mostly located in the center of Ruijin City and the radius of the center.

(3) Whether or not there is abandonment of arable land plots in the hilly mountainous areas of Gannan is affected by a combination of socio-economic conditions, natural resources, farming conditions, and economic location, with altitude, the degree of contiguity of arable land, and population density being the dominant factors, which reflects the difficulty coefficient of arable land cultivation and the efficiency of cultivation to a certain degree, which limits the production of foodstuffs in the hilly mountainous areas of Gannan. The interactions of elevation, concentration, field regularity, and per capita cultivated area increase the spatial variability of arable land abandonment in the hilly mountainous areas of Gannan, which is reflected in the common negative effects of increased difficulty in farming and difficulty in obtaining equivalent economic returns. Whether or not the phenomenon of non-grain occurs in arable land plots in the hilly mountainous areas of Gannan is affected by socio-economic conditions, farming conditions, and economic location, among which the proportion of paddy fields, the price of land transfer, the area of arable land, and the urban-rural gradient are the dominant factors, which reflect the fact that the level of non-grain is affected by the social and economic conditions, and the economic location. Non-grain level is less affected by natural conditions and mainly affected by socio-economic conditions. Compared with the abandonment of arable land, the phenomenon of non-grain occurs more often in regions with faster economic development, where farmers are driven by economic interests and take the initiative to plant cash crops to improve their family incomes. The tendency to plant non-grain crops on arable land is more serious due to the interaction of such driving factors as the proportion of paddy fields, land transfer prices, arable land area, and the urban-rural gradient.

This study comprehensively analyses the spatial distribution characteristics and driving factors of the phenomenon of arable land abandonment and non-grain based on existing research, which is of certain reference significance to other arable land in the hilly mountainous areas of Gannan, and to a certain extent complements a series of existing studies. In the future research program, more attention should be paid to more arable land issues, such as the driving factors and spatial and temporal evolution patterns of arable land planted under greenhouses, and the research area should be further expanded so that the research results can be more representative and practically meaningful and provide scientific basis for the agricultural departments to formulate relevant policies.

Declarations

Review and/or approval by an ethics committee was not needed for this study as it didn't involve direct interaction with individuals or their sensitive data. For the same reason, there was no reason to seek informed consent.

Data availability statement

The data used in the article is confidential, so it's difficult to share, sorry!

CRediT authorship contribution statement

Hao Yuan: Writing – original draft. **Yonglin Chen:** Writing – review & editing, Resources, Methodology. **Jianping Lin:** Methodology, Investigation. **Yunping Zhang:** Resources, Methodology, Conceptualization. **Chenhui Zhu:** Visualization, Software, Resources.

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.

Acknowledgements

The project was supported by the Science and Technology Project of Jiangxi Provincial Department of Education (GJJ2201215) and the Humanities and Social Sciences Project of Jiangxi Provincial Colleges and Universities (GL20225).

References

[1] T. Perdana, et al., Scenarios for handling the impact of COVID-19 based on food supply network through regional food hubs under uncertainty, Heliyon 6 (10) (2020) e05128, https://doi.org/10.1016/j.heliyon.2020.e05128.
[2] B.D.L. Fitt, et al., Impacts of changing air composition on severity of arable crop disease epidemics, Plant Pathol. 60 (1) (2011) 44–53, https://doi.org/10.1111/j.1365-3059.2010.02413.x.
[3] R.D. Semba, et al., The potential impact of climate change on the Micronutrient-rich food supply, Adv. Nutr. 13 (1) (2022) 80–100, https://doi.org/10.1093/advances/nmab104.
[4] H. El Ghobashy, et al., Development and evaluation of a dual-purpose machine for chopping and crushing forage crops, Heliyon 9 (4) (2023) e15460, https://doi.org/10.1016/j.heliyon.2023.e15460.
[5] A. Kozielec, et al., Challenges to food security in the Middle East and north africa in the context of the Russia-Ukraine conflict, Agriculture-Basel 14 (1) (2024), https://doi.org/10.3390/agriculture14010155.
[6] T.T. Nguyen, et al., Interstate war and food security: implications from Russia's invasion of Ukraine, Front. Sustain. Food Syst. 7 (2023), https://doi.org/10.3389/fsufs.2023.1080696.
[7] Z. Gebeltova, et al., Geopolitical risks for Egypt wheat supply and trade, Front. Sustain. Food Syst. 7 (2023), https://doi.org/10.3389/fsufs.2023.1137526.
[8] Y. Su, et al., Trade-offs between economic benefits and environmental impacts in non-grain expansion: a case study in the eastern plain of China, Environ. Sci. Pollut. Control Ser. (2024), https://doi.org/10.1007/s11356-024-31930-0.
[9] L. Fei, M. Shuang, L. Xiaolin, Changing multi-scale spatiotemporal patterns in food security risk in China, J. Clean. Prod. 384 (2023), https://doi.org/10.1016/j.jclepro.2022.135618.
[10] S. Savary, et al., Revisiting food security in 2021: an overview of the past year, Food Secur. 14 (1) (2022) 1–7, https://doi.org/10.1007/s12571-022-01266-z.
[11] M.K. Bashir, S. Schilizzi, How disaggregated should information be for a sound food security policy? Food Secur. 5 (4) (2013) 551–563, https://doi.org/10.1007/s12571-013-0271-y.
[12] A. Guo, et al., Cropland abandonment in China: patterns, drivers, and implications for food security, J. Clean. Prod. 418 (2023), https://doi.org/10.1016/j.jclepro.2023.138154.
[13] B. Qiu, et al., Urban expansion or poor productivity: explaining regional differences in cropland abandonment in China during the early 21st century, Land Degrad. Dev. 31 (17) (2020) 2540–2551, https://doi.org/10.1002/ldr.3617.
[14] C. Alcantara, et al., Mapping the extent of abandoned farmland in Central and Eastern Europe using MODIS time series satellite data, Environ. Res. Lett. 8 (3) (2013), https://doi.org/10.1088/1748-9326/8/3/035035.
[15] S. Estel, et al., Mapping farmland abandonment and recultivation across Europe using MODIS NDVI time series, Rem. Sens. Environ. 163 (2015) 312–325, https://doi.org/10.1016/j.rse.2015.03.028.
[16] X. Guan, et al., Regulation and optimization of cultivated land in different ecological function areas under the guidance of food security goals-a case study of Mengjin County, Henan Province, China, Front. Environ. Sci. 11 (2023), https://doi.org/10.3389/fenvs.2023.1115640.
[17] Z. Zhu, et al., Spatial evolution, driving mechanism, and patch prediction of grain-producing cultivated land in China, Agriculture-Basel 12 (6) (2022), https://doi.org/10.3390/agriculture12060860.
[18] J. Zhang, et al., Is there a regularity: the change of arable land use pattern under the influence of human activities in the Loess Plateau of China? Environ. Dev. Sustain. 23 (5) (2021) 7156–7175, https://doi.org/10.1007/s10668-020-00909-5.
[19] S. Li, et al., Spatiotemporal characteristics of cultivated land use eco-efficiency and its influencing factors in China from 2000 to 2020, Journal of Arid Land 16 (3) (2024) 396–414, https://doi.org/10.1007/s40333-024-0094-z.
[20] C.M. Musafiri, et al., Adoption of climate-smart agricultural practices among smallholder farmers in Western Kenya: do socioeconomic, institutional, and biophysical factors matter? Heliyon 8 (1) (2022) e08677 https://doi.org/10.1016/j.heliyon.2021.e08677.
[21] Z. Yu, et al., Assessment of land degradation risks in the Loess Plateau, Land Degrad. Dev. 35 (7) (2024) 2409–2424, https://doi.org/10.1002/ldr.5069.
[22] G. Chen, Comparative spatial distribution simulation of plateau mountain cultivated land based on spatial multi-scale model, yunnan central urban agglomeration area, China, Pol. J. Environ. Stud. 32 (4) (2023) 3063–3080, https://doi.org/10.15244/pjoes/161379.
[23] M. Mohsin, A.A. Khan, Analysis of the determinants of agricultural land conversion (alc) into housing colonies in bahawalpur city, Pakistan, Pakistan J. Agric. Sci. 54 (3) (2017) 725–730, https://doi.org/10.21162/pakjas/17.2643.
[24] E. Hatna, M.M. Bakker, Abandonment and expansion of arable land in europe, Ecosystems 14 (5) (2011) 720–731, https://doi.org/10.1007/s10021-011-9441-y.
[25] Q. Yang, et al., Does fallowing cultivated land threaten food security? Empirical evidence from Chinese pilot provinces, Sustainability 11 (10) (2019), https://doi.org/10.3390/su11102836.
[26] T. Shi, et al., Analysis of farmland abandonment at parcel level: a case study in the mountainous area of China, Sustainability 8 (10) (2016), https://doi.org/10.3390/su8100988.
[27] X. Deng, et al., Does farmland abandonment harm agricultural productivity in hilly and mountainous areas? evidence from China, J. Land Use Sci. 16 (4) (2021) 433–449, https://doi.org/10.1080/1747423x.2021.1954707.
[28] S. Dong, et al., Extent and spatial distribution of terrace abandonment in China, J. Geogr. Sci. 33 (7) (2023) 1361–1376, https://doi.org/10.1007/s11442-023-2133-7.
[29] Y. Wang, A. Yang, Q. Yang, The extent, drivers and production loss of farmland abandonment in China: evidence from a spatiotemporal analysis of farm households survey, J. Clean. Prod. 414 (2023), https://doi.org/10.1016/j.jclepro.2023.137772.

[30] C. Donnison, et al., Land-use change from food to energy: meta-analysis unravels effects of bioenergy on biodiversity and cultural ecosystem services, Environ. Res. Lett. 16 (11) (2021), https://doi.org/10.1088/1748-9326/ac22be.
[31] L.M. Lehmann, et al., Productivity and economic evaluation of agroforestry systems for sustainable production of food and non-food products, Sustainability 12 (13) (2020), https://doi.org/10.3390/su12135429.
[32] J. Wang, C. Dai, Identifying the spatial-temporal pattern of cropland's non-grain production and its effects on food security in China, Foods 11 (21) (2022), https://doi.org/10.3390/foods11213494.
[33] I. Zambon, et al., Rural districts between urbanization and land abandonment: undermining long-term changes in mediterranean landscapes, Sustainability 10 (4) (2018), https://doi.org/10.3390/su10041159.
[34] K.-L. Wang, et al., Spatiotemporal pattern evolution and influencing factors of green innovation efficiency: a China?s city level analysis, Ecol. Indicat. 146 (2023), https://doi.org/10.1016/j.ecolind.2023.109901.
[35] Y. Liang, C. Xu, Knowledge diffusion of Geodetector: a perspective of the literature review and Geotree, Heliyon 9 (9) (2023) e19651, https://doi.org/10.1016/j.heliyon.2023.e19651.
[36] J. Li, et al., Analysis of spatio-temporal changes and driving forces of cultivated land in China from 1996 to 2019, Front. Environ. Sci. 10 (2022), https://doi.org/10.3389/fenvs.2022.983289.
[37] L. Li, et al., The quantitative impact of the arable land protection policy on the landscape of farmland abandonment in Guangdong province, Rem. Sens. 14 (19) (2022), https://doi.org/10.3390/rs14194991.
[38] W. Meijninger, et al., Identification of early abandonment in cropland through radar-based coherence data and application of a Random-Forest model, Global Change Biology Bioenergy 14 (7) (2022) 735–755, https://doi.org/10.1111/gcbb.12939.
[39] X. Liang, et al., Formation mechanism and sustainable productivity impacts of non-grain croplands: evidence from Sichuan Province, China, Land Degrad. Dev. 34 (4) (2023) 1120–1132, https://doi.org/10.1002/ldr.4520.
[40] Y. Li, et al., Characteristics and driving forces of non-grain production of cultivated land from the perspective of food security, Sustainability 13 (24) (2021), https://doi.org/10.3390/su132414047.