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Changes in cultivated land patterns and driving forces in the Three Gorges Reservoir area, China, from 1992 to 2015

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Abstract: Changes of cultivated land patterns caused by major water conservation projects are rarely reported. We selected the Three Gorges Reservoir area in China to study the change in area and landscape pattern of the cultivated land in the head, central, and tail areas of the reservoir that took place between 1992 and 2015; we then studied the spatial distribution of the cultivated land in the three parts of the reservoir; finally, we studied the driving forces behind the changes in the cultivated land. The results derived are as follows. (1) During the construction of the Three Gorges Project (TGP, 1992–2015), the area of cultivated land around the reservoir decreased by 30.23 million ha. This reduction occurred in phases: the most severe change in cultivated land occurred during the later stage of the project (2002–2010); only 0.62 million ha of cultivated land did not change between 1992 and 2015. (2) Spatial pattern analysis showed that the cultivated land in the three parts of the reservoir changed from a northern distribution to a southern distribution; thus, the area of cultivated land in the north decreased over the time period. The area of cultivated land in the head and tail areas decreased by varying degrees, while it increased in the central area over the 23 years, indicating that the change in cultivated land showed regional differences. (3) The TGP, the policy of reverting farmland to forest, and urbanization were the main driving factors for the change of cultivated land, but there were differences in their impacts at different stages. (4) According to the patch dynamics of the land cover change, the

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degree of change gradually intensified during the early and later stages of the project and then stabilized during the operational period. Our research provides scientific support for the protection of cultivated land resources and food security in the reservoir area and for the coordination of social and economic development, which is of great significance to sustainable development in the reservoir area.

Keywords: Agricultural land change; Three Gorges Reservoir area; Landscape index; The standard deviation ellipse; Cultivated land; Driving forces

Introduction

Cultivated land is a natural resource for human survival and provides the basic functions of contributing to food security and meeting the demands of industrialization and urbanization (Horst and Marion 2019). The conversion of cultivated land may reflect regional industrialization and urbanization to a certain extent (Cheng et al. 2015). Contemporary studies of cultivated land use have primarily focused on temporal and spatial distributions, as well as influencing factors. Of these factors, most pertain to the temporal and spatial patterns of cultivated land change, with a focus on the conversion of cultivated land (Hatna and Bakker 2011; Sun and Zhou 2016). A study of cultivated land change at the regional scale is often intended to assess the effects of urbanization and industrialization (Xiao et al. 2019). The temporal and spatial variability of cultivated land in mountainous areas that result from major water conservancy projects has rarely been studied (Strehmel et al. 2016). The Three Gorges Reservoir area is located in a mountainous area and includes a major water conservancy project. For this reason, this study on the temporal and spatial variability of cultivated land in the Three Gorges Reservoir area has great significance.

The Three Gorges Project (TGP) has been the largest hydropower project in the world since 2009, and it is a freshwater reservoir and ecological barrier zone of strategic status in China. The cultivated land in the reservoir area not only contributes to economic production, but the environment and the utilization and management of the land also play strategic roles in social and economic development and in environmental security (Lam 2015).

The cultivated area around the Three Gorges Reservoir area is in decline (Feng and Xu 2015), which has serious implications for food security and the livelihood of farmers. Current studies regarding cultivated land in the reservoir area have focused on the early and later stages of the project (Chen and Wang 2010), although there have been additional impacts on land use patterns since its official operation began (Li et al. 2017; Song et al. 2017; Deng and Shao 2018). However, few researchers have explored these changes, particularly the change in cultivated land. In addition, there have been few studies regarding the impact of the policy of reverting cultivated land to forest, or the impact of the construction of the TGP on cultivated land at present. For example, Shao et al. (2018) adopted binary logistic regression analysis to analyze the relationship between natural factors and social and economic factors, and on the resulting land use changes. Liang and Li (2019) explored the farmland change mechanism in the hinterland of the Three Gorges Reservoir from the perspective of social economy.

Cultivated land in the reservoir area has been mainly affected by urbanization (Chen and Wang 2010; Seeber et al. 2010), the policy of reverting cultivated land to forest (Cao et al. 2013; Feng and Xu 2015), and the TGP (Xu et al. 2011; Austin et al. 2013; Cao et al. 2013). Among these factors, urbanization refers to the conversion of cultivated land to built-up areas (Song et al. 2015; Zhao et al. 2017b; Kang et al. 2018), and its indirect impacts have mainly manifested in the transfer of the rural labor force, which has led to cultivated land abandonment (Li and Li 2017; Chen et al. 2018; Su et al. 2018; Li and Li 2019). The reversion of cultivated land to forest has taken place over two time periods, notably from 2000 to 2006 and from 2014 to 2015, with the impacts mainly reflected by the conversion of cultivated land on steep slopes (Guo and Gong 2016; Wang et al. 2017; Zhao et al. 2017a; Wang and Yang 2018). The direct impacts of the TGP refer to the conversion of cultivated land to a body of water (Strehmel et al. 2016). The inundation of cultivated land, forest grassland, and urban villages caused by river damming and experimental water storage has led to this increase in water coverage. The indirect impacts include a high demand for cultivated land caused by immigration, and the occupation of cultivated land due to resettlement, relocation, and support for facility construction (Xu et al. 2011; Xu et al. 2015). The driving forces of cultivated land change in the reservoir area have varied across different periods, but current studies rarely discuss them with respect to different stages and different regions, particularly in reference to project operation. It has been difficult to quantify the overall change in cultivated land in the reservoir area because of the various driving forces.

In this background, we set three goals for this study, namely (1) to quantitatively study the changes in cultivated land during the early, later, and operating stages of the project; (2) to determine the spatial distribution of cultivated land in the Three Gorges Reservoir area during the aforementioned three periods; and (3) to assess the impact of driving forces on the change in cultivated land during different periods in the reservoir area.

1 Materials and Methods

1.1 Study area

The Three Gorges Reservoir area (106°00'-111°50'E, 29°16'-31°25'N) is situated at the junction of the Sichuan Basin and the middle and lower reaches of the Yangtze River Plain (Figure 1). It covers an area of 578 million ha and is a key area for soil and water conservation in China (Ye et al. 2013). The study area has a typical subtropical monsoon climate, with annual average temperatures and precipitation ranging from 17°C to 19°C, and 1000–1200 mm, respectively (Xia et al. 2013). The reservoir area is rich in ecological resources, and the dominant vegetation types include coniferous, broad-leaved, mixed, and bamboo forests, and shrubland. Mountains account for 74% of the total land area, and low hills, flood plains, valleys, and water constitute the remaining 26% (Teng et al. 2017).

To reflect the spatial and temporal variability of cultivated land related to the construction, water storage, and resettlement stages of the TGP, the period 1992–2015 was selected as the study period. Pre-construction was represented by 1992 conditions, the later stage of construction was represented by 2002 conditions, and project operation was represented by 2010 conditions. The period from 1992 to 2002 represented the early stage of the project (hereafter referred to as the early stage of the project). The period from 2002 to 2010 represented the later construction and completion stages (hereafter referred to as the later stage of the project). Finally, the period from 2010 to 2015 represented the formal operational stage (hereafter referred to as the operational stage of the project). Spatially, the Three Gorges Reservoir area was divided into the Chongqing and Hubei sections. According to previous studies, 26 counties (districts) in the reservoir area were then assigned to the head, central, and tail areas of the reservoir (Figure 2).

1.2 Data

Two types of data were used in this study: remote sensing-based land cover maps and statistical data. The remote sensing data consisted of three-stage land use data representing the changing characteristics of the cultivated land in the reservoir area between 1992 and 2015 (Figure 3). Land use data for 1992 and 2002 were obtained

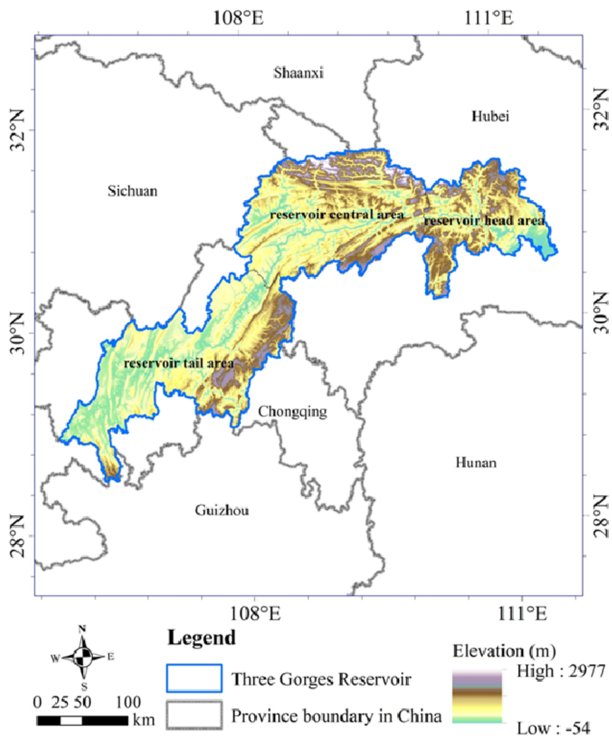

Figure 1 The Map of the Three Gorges Reservoir.

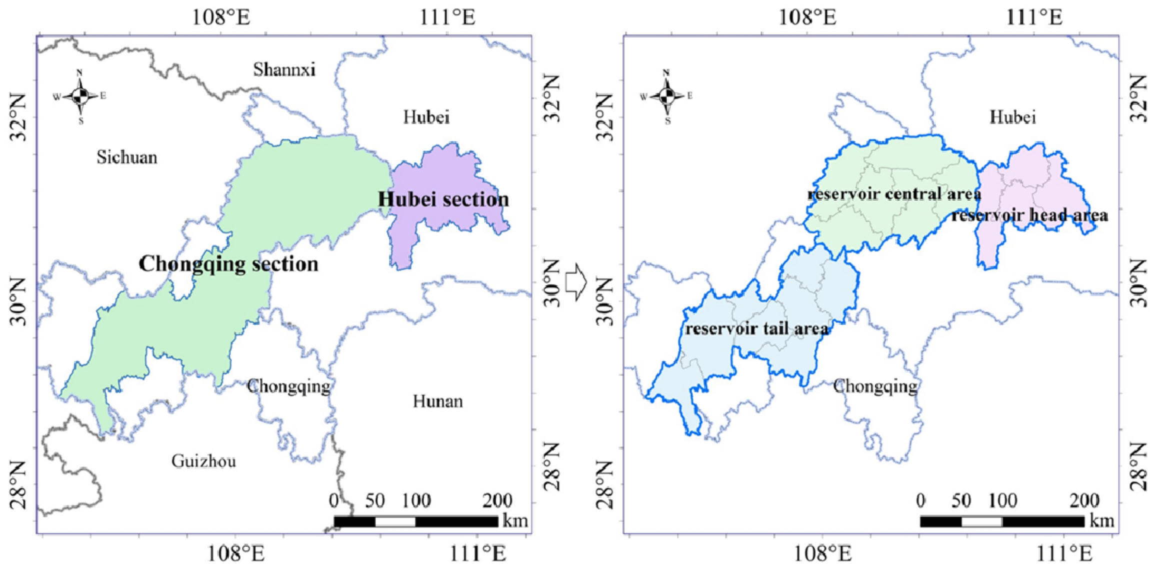

Figure 2 The partition process of the Three Gorges Reservoir area in this study.

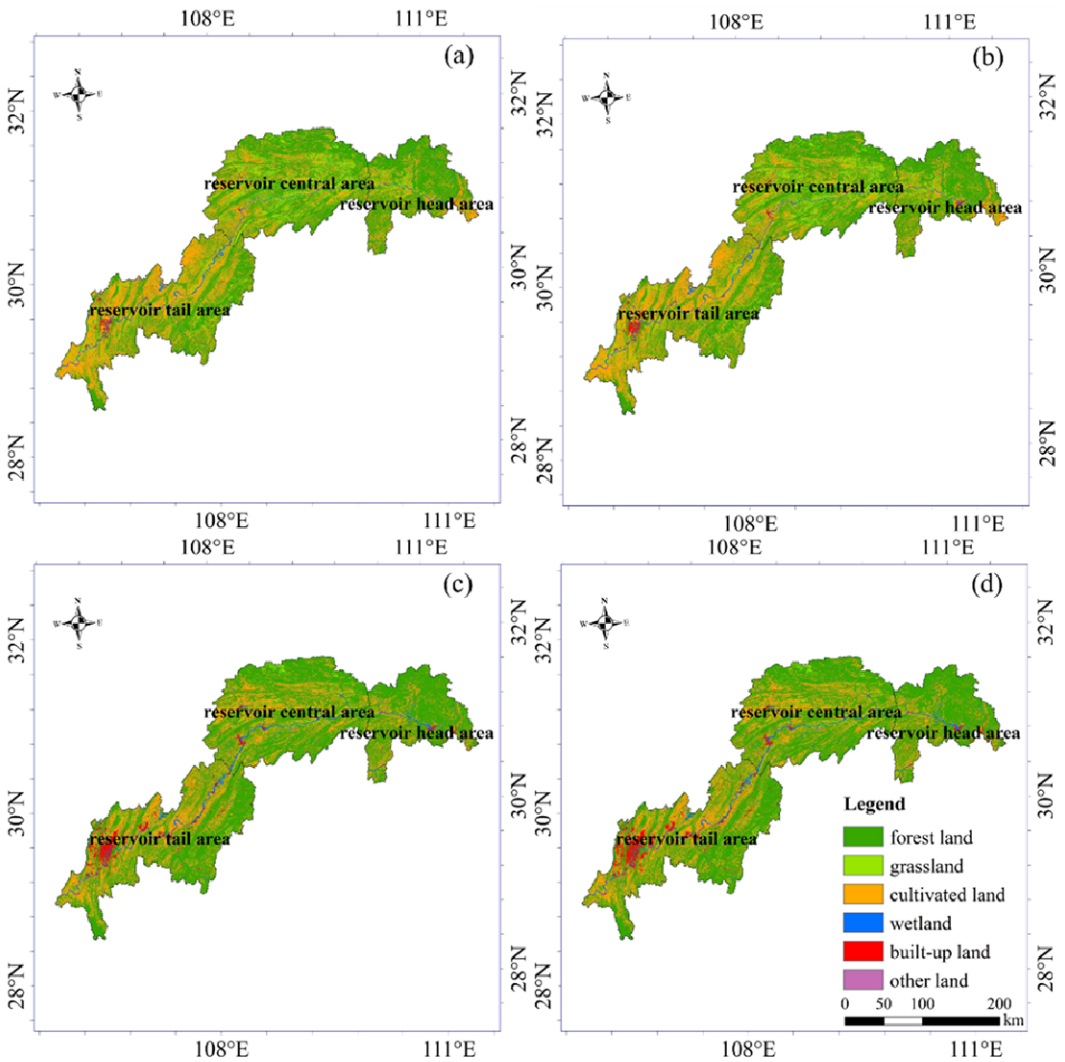

Figure 3 Land use data of the Three Gorges Reservoir area for 1992(a), 2002(b), 2010(c) and 2015(d).

from the Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences. Land use data for 2010 and 2015 were obtained from the Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences.

Statistical data for the area where cultivated land was converted to forest, and the number of immigrants in the reservoir area, were used to analyze the driving factors of cultivated land change. Statistics regarding the cultivated land converted to forests in the Three Gorges Reservoir area of Chongqing and Hubei were collected from the Chongqing Forestry Bureau and the Forestry Department of Hubei Province, respectively. The number of total immigrants, and the number of immigrants from Chongqing were obtained from the Chongqing Immigration Bureau and Yanan Cui (2009).

1.3 Methods

This study was conducted in four steps. First, the changes in the area and landscape pattern of the cultivated land in the reservoir area were analyzed from 1992 to 2015 using a landscape index. Then, standard deviation analysis was used to analyze the spatial pattern change characteristics of the cultivated land. Finally, we estimated the conversion of cultivated land during the period from 1992 to 2015 using a transfer matrix. The driving forces behind the cultivated land change were analyzed using Pearson correlation analysis.

1.3.1 Analysis of cultivated land spatial configuration

During this step, we mainly analyzed the landscape pattern and area change in cultivated land through landscape analysis. Landscape index analysis was employed to quantify the landscape pattern information of the cultivated land, including its structural composition, morphological changes, and spatial configuration (Cheng et al. 2015). Thus, we calculated the landscape indices of the Three Gorges Reservoir area using arable land data for the reservoir area in 1992, 2002, 2010, and 2015. Indicators that reflected the spatial pattern and fragmentation of the cultivated land in the reservoir area were selected as follows: total landscape area (TA), mean patch size (MPS), and landscape shape index (LSI). TA was used to measure the area of cultivated land and its conversion over the four periods. MPS measured the average area of each cultivated plaque over the four periods. LSI denoted a shape description of the cultivated land and its changes. The formula for LSI is as follows:

$$\mathrm{LSI}=0.25^{*}\sum_{i=1}^{n}c_i/\sqrt{\sum_{i=1}^{n}a_i} \quad (1)$$

where c_i is the circumference of the i^{th} patch, and a_i is the area of the i^{th} patch. The index value of the landscape shape of a square patch is 1. The higher the index value, the more irregular the patch shape.

1.3.2 Analysis of spatial distribution of cultivated land

Standard deviation analysis was used to describe the point shift in the spatial distribution, as well as to analyze the landscape pattern and the development of land cover type (Shi et al. 2018). It produced three results: the corner, the X-axis standard deviation, and the Y-axis standard deviation. The lengths of the X-axis and Y-axis indicate the intensity of the distribution trend in each direction, and the corner indicates the main direction of the spatial distribution of the land type. We used this method to determine the geographical center of the cultivated land in 1992, 2002, 2010, and 2015.

1.3.3 Analysis of driving factors of cultivated land change

During this step, we mainly analyzed the type of change in the cultivated land and its driving forces by using a transfer matrix and Pearson correlation analysis. The land use transfer matrix has been used to comprehensively and concretely analyze the quantity and direction of regional land use change (Sbafizadeh-Moghadam et al. 2019); thus it has been widely employed in land use change research. To determine the change in cultivated land area during the three study periods, we employed the land use data to study the simultaneous change in various land use types and cultivated land using the transfer matrix method. We obtained the conversion to built-up land, to grassland and other land, to submerged land, and to forest using the transfer matrix. The conversion to built-up land area, to forest area, and to submerged area represented the direct impacts of urbanization (Chen and Wang 2010; Seeber et al. 2010), reverting cultivated land to forest (Cao et al. 2013; Feng and Xu 2015), and construction of the TGP (Xu et al. 2011; Austin et al. 2013; Cao et al. 2013), respectively. Thus, the rankings of the driving factors were obtained for the corresponding area.

Pearson correlation analysis was used to show the relationships between the driving forces and the change in cultivated land area (Chu et al. 2019). We established a correlation between the conversion to built-up land area, conversion to grassland and other land area, conversion to submerged area, conversion to forest area, and the area of cultivated land change during the three periods from 1992 to 2015.

2 Results and Discussion

2.1 Change in spatial configuration of cultivated land

2.1.1 Land area change

We used TA to calculate the area of cultivated land and its change during each period (Table 1). In 1992, the total area of cultivated land in the reservoir area was 191.83 million ha, of which the head, central, and tail areas accounted for 15.4%, 29.1%, and 55.5%, respectively. Cultivated land area decreased over the following 23 years by a total of 30.23 million ha. The original cultivated land decreased by 90.59 million ha, while other land types were converted to 60.61 million ha of cultivated land. During the early, later, and operational stages of the project, cultivated land was reduced by 2.13 million ha, 25.45 million ha, and 2.65 million ha, respectively. The area of cultivated land in the head and tail areas decreased to varying degrees, while it increased in the central area during the 23 years.

2.1.2 Change in patch dynamics

The change in patch size may reflect the change in cultivated land plot size. Using the landscape index method, we analyzed MPS and LSI during the three periods from 1992 to 2015 (Table 2). The results showed that the LSI values for patches across the three periods in the head, central, and tail areas decreased by 7.9, 19.3, and 20.9, respectively. The LSI results also showed that the shape of the

Table 1 Area change of cultivated land from 1992 to 2015 in the Three Gorges Reservoir area.

Change of cultivated land /year		Total land area (million ha)	Area (%)		
			Head area	Central area	Tail area
Cultivated land	1992	191.83	15.4	29.1	55.5
	2002	189.7	15.4	30.3	54.3
	2010	164.25	14.5	37.6	47.8
	2015	161.6	14.7	38	47.4
Transferred to Cultivated land	1992-2002	0.85	58.1	24.5	17.4
	2002-2010	59.59	17.4	52.5	30.1
	2010-2015	0.17	36.1	16.2	47.7
Lost cultivated land	1992-2002	2.99	23.6	31.6	44.7
	2002-2010	84.77	18.6	28.8	52.6
	2010-2015	2.83	8.2	15.8	76

Table 2 Change of cultivated landscape index in the Three Gorges Reservoir area.

Change of cultivated land /year		Mean Patch Size (ha)			Landscape Shape Index		
		Head area	Central area	Tail area	Head area	Central area	Tail area
Cultivated land	1992	47.4	14.1	14.7	132.7	159.2	132.9
	2002	44.0	17.9	15.2	139.3	151.2	132.0
	2010	28.0	19.1	16.2	123.9	139.7	111.6
	2015	26.4	18.8	15.8	124.8	139.9	112.0
Transferred to cultivated land	1992-2002	4.7	7.2	14.8	8.9	9.8	16.2
	2002-2010	1.0	2.9	1.8	189.9	198.5	156.0
	2010-2015	0.2	0.3	0.5	19.2	11.0	15.8
Lost cultivated land	1992-2002	12.2	16.3	8.8	14.3	18.4	19.4
	2002-2010	2.7	2.0	2.7	200.8	188.1	161.4
	2010-2015	2.5	2.9	1.6	32.7	20.3	20.9

cultivated land plots became more uniform. The MPS values across the three periods for the head, central, and tail areas changed by -21, 4.7, and 1.1, respectively, indicating that the use of cultivated land in the central and tail areas of the reservoir increased. However, it decreased in the head area. This phenomenon showed that the cultivated land increased in scale in the central and tail areas, but tended to be operated by small farmers in the head area.

The MPS values for areas that were converted to cultivated land in the head, central, and tail areas decreased by 4.5, 6.9, and 14.3 ha, respectively, over the three periods. This indicates that the scale of agriculture was gradually decreasing. This is similar to the cultivated land change that results from urbanization (Lee and Huang 2018). The LSI first increased and then decreased between 1992 and 2015. However, the LSI in 2015 was still lower than that in 1992, indicating that the patches that were converted to arable land gradually decreased in size and became more regular in shape. The MPS values for converted cultivated land in the head and tail areas decreased, while in the central area, the values first decreased and then increased. The MPS and LSI trends were nearly the same, indicating that the cultivated land change gradually intensified from the early stage to the later stage of project construction, and then tended to remain stable (Table 2). The area of cultivated land change during the operational period was stable. This may have been because the factors affecting cultivated land change caused by resettlement and water storage diminished with the completion of the TGP. Cultivated land change during this period was more consistent with that of urbanization (Liu et al. 2013).

2.2 Distribution change in cultivated land

The standard deviation analysis method reflected the distribution and center of cultivated land, and showed changes in the reservoir area. Figure 4a shows the standard deviation ellipse for the cultivated land distribution, and Figure 4b shows the distribution of the conversion of cultivated land between 1992 and 2015. The spatial distribution of the cultivated land in the three regions showed a transfer of land area from north to south; the area of cultivated land in the north decreased. Here, the distribution of cultivated land in the head and central areas shifted from the northwest to the southeast, and in the tail area, it moved from the northeast to the southwest. Additionally, the center of the cultivated land moved in a manner similar to that of the distribution (Figure 4a).

The direction of spatial variability in the cultivated land change area was not consistent in any of the three regions, indicating that the driving factors played different roles in each region (Figure 4b).The center of the cultivated land area, and the distribution in the head, central, and tail areas of the reservoir all shifted southward, which was similar to the observations of Cao et al. (2013). However, a similar directional shift was observed for the center of cultivated land converted from other land types, and for the center of the cultivated land lost during the period of 1992 to 2015. The center of transferred from cultivated land area and the center of transferred to cultivated land area gradually overlapped during the later and operational stages. This indicates that the conversion of cultivated land became increasingly concentrated.

2.3 Driving factors of cultivated land change

2.3.1 Conversion type

We used a transfer matrix to study the area of land converted from cultivated land to other land types (Table 3). The change in cultivated land area

Table 3 Conversion of cultivated land during 1992 and 2015 in the Three Gorges Reservoir area.

Regional Change/year		Types of land use/ha				
		Cultivated land	Forest land	Grassland	Water body	Built-up land
Reservoir head area	1992-2002	287,654	1697	1466	248	2875
	2002-2010	134,426	355,882	2596	7707	8125
	2010-2015	236,442	2163	22	98	1101
Reservoir central area	1992-2002	548,816	2888	3007	189	3353
	2002-2010	308,029	207,651	16,647	9756	8828
	2010-2015	613,599	1544	11	311	2486
Reservoir tail area	1992-2002	1,052,131	2487	773	437	10,446
	2002-2010	608,834	139,754	20,277	8284	60,340
	2010-2015	765,103	1014	54	324	18,426

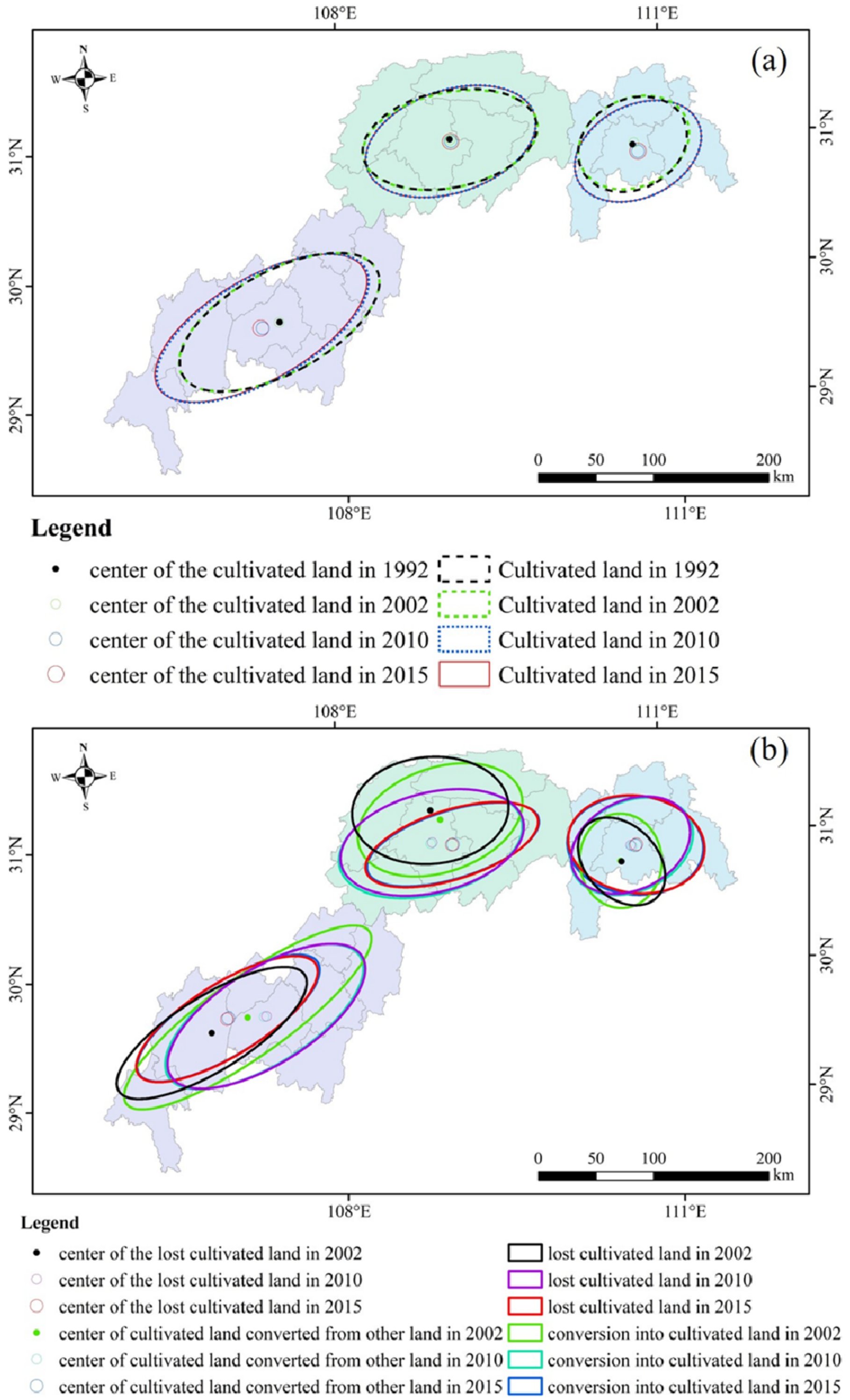

Figure 4 Standard deviation ellipse of cultivated land (a), standard deviation ellipse of cultivated land change area from 1992 to 2015 (b).

was reflected in the conversion type. The loss of cultivated land during the early stage of the project was mainly because of conversion to built-up land. The head, central, and tail areas were 2875 ha, 3,353 ha, and 10,446 ha, respectively. During the later stage of the project, cultivated land was mainly converted to forest land with respective regional losses of 355,882 ha, 207,651 ha, and 139,754 ha. During the operational period of the project, cultivated land was mainly converted to built-up land with respective regional losses of 1,101 ha, 2,486 ha, and 18,426 ha, indicating that the policy of reverting cultivated land to forest and the processes of urbanization had great impact on cultivated land change. Additionally, the changes in cultivated land in the Three Gorges Reservoir area were similar to those resulting from rapid urbanization in China (Xiao et al. 2018; Yu et al. 2019). The stable cultivated land amounted to only 0.62 million ha between 1992 and 2015, which accounted for 0.38% of the cultivated area in 2015. In the head, central, and tail areas, the stable cultivated land amounted to 72,533 ha, 0.18 million ha, and 0.37 million ha, respectively.

2.3.2 Driving factors analysis

The driving factors behind the cultivated land change in the Three Gorges Reservoir area were divided into three types: engineering construction (Xu et al. 2011; Austin et al. 2013; Cao et al. 2013), reverting cultivated land to forest (Cao et al. 2013; Feng and Xu 2015), and urbanization

(Chen and Wang 2010; Seeber et al. 2010). Of these types, urbanization was the main driving force for cultivated land change during the early and operational stages. During the three stages of the project, the areas of cultivated land that were converted to built-up land were 16,674, 77,293, and 22,013 ha, respectively, which accounted for 52%, 9%, and 78% of the area of cultivated land, respectively (Table 3). A large area of cultivated land was occupied by construction works in the Three Gorges Reservoir area (Cao et al. 2013). Additionally, our research showed that urbanization had the strongest impact in the tail area, and the indirect cause of cultivated land abandonment was most significant in the central area. The area of cultivated land converted to urban land across all stages was highest in the tail area. Land abandonment mainly manifested in the conversion of cultivated land to grassland and other land use types. This phenomenon mainly occurred during the early and later stages of the project and gradually intensified during the later stage. The area of cultivated land converted to grassland and other land use types in the central area was higher during the early stage, while it was high in the tail area during the later stage (Figure 5). This showed that the livelihood strategy changed for some farmers in the reservoir area to reduce their dependence on and demand for cultivated land, particularly in the central and tail areas.

The impacts of the policy of reverting cultivated land to forest were mainly concentrated during the later and operational stages of the project. The impacts during the later stage were the most severe. During this period, the areas of reverted cultivated land in the three regions were 35,500, 133,000, and 213,300 ha, respectively, accounting for 22%, 54%, and 27%, respectively, of the converted area of cultivated land during that period (Figure 6). Cao et al. (2013) noted that the policy of reverting farmland to forest was one of the main driving forces of the cultivated land change. The findings of this study showed that the central area was greatly affected by the cultivated-land-to-forest policy.

The TGP had significant direct and indirect effects on the head and central areas of the reservoir, respectively. From 1992 to 2015, 27,400 ha of cultivated land was flooded, and the percentages of inundated cultivated land over the three periods were 3%, 94%, and 3%, respectively. In the respective head and tail areas, 1.8% and 0.8% of cultivated land were converted to water during the later stage of the project. This research also showed that the head area was greatly affected by the impoundment of the TGP. The number of immigrants in the central area reached 0.79 million, accounting for 64% of the total number of immigrants, showing that the region was greatly affected by the influx of people. The percentages of converted cultivated land during the three periods were 0.7%, 99.2%, and 0.1%, respectively. This showed that cultivated land reclamation significantly increased, and the distribution was more strongly during the later stage (Figure 7).

Table 4 shows that the area of lost cultivated land, and the area converted to cultivated land, were both significantly positively correlated with the area converted from cultivated land to grassland and the submerged area ($P<0.01$). Previous studies have shown that urbanization indirectly led to cultivated land abandonment by attracting labor from the countryside in the Three Gorges Reservoir area, which is reflected in the area of arable land converted to grassland and other land areas (Zhang et al. 2009). Therefore, the correlation coefficient showed that the change in cultivated land was most significantly indirectly affected by urbanization, and was most significantly directly affected by the TGP (Wang et al. 2016; Wang et al. 2018).

At the same time, the lost cultivated land was also significantly positively correlated with the area of cultivated land reverted to forest ($P<0.05$). Although its correlation coefficient was not higher

Table 4 Pearson correlation coefficients between cultivated land change and driving forces in the Three Gorges Reservoir area.

Changing area of cultivated land	Conversion into forest area	Conversion into built-up land area	Submerged area	Conversion into grassland and other land area
Lost cultivated land	0.675*	0.414	0.928**	0.872**
Conversion into cultivated land	0.608	0.823**	0.878**	0.939**

Note: ** Significant at the 1% confidence level.* Significant at the 5% confidence level.

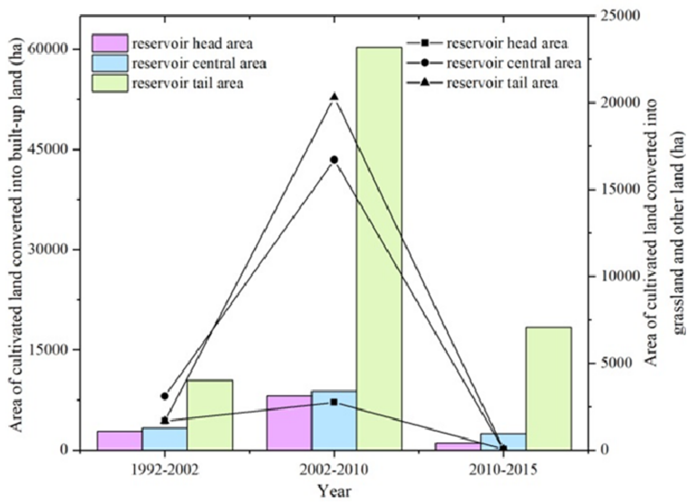

Figure 5 Area of cultivated land converted into built-up land and grassland and other land in the Three Gorges Reservoir area.

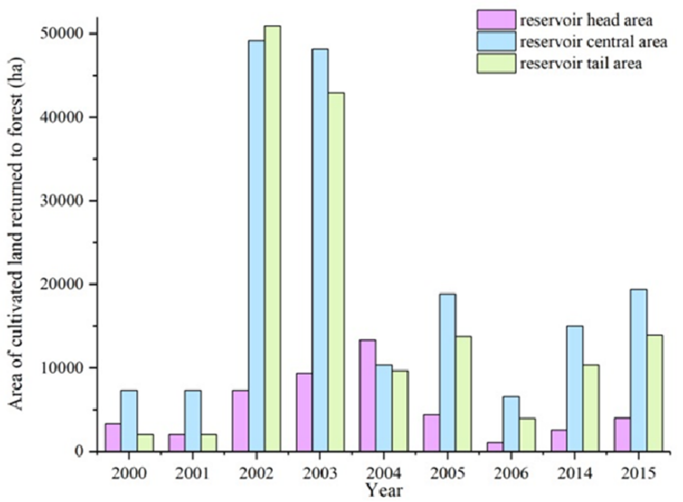

Figure 6 Area of cultivated land returned to forest in the Three Gorges Reservoir area (source: Chongqing Forestry Bureau, Hubei Forestry Department).

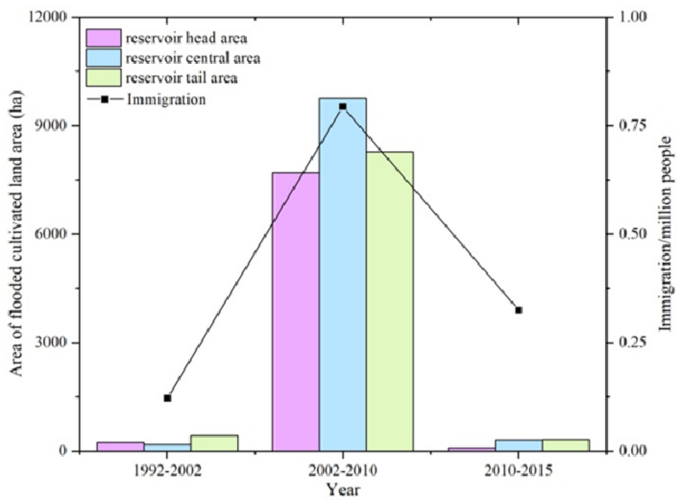

Figure 7 Area of flooded cultivated land area and the number of immigrants in the Three Gorges Reservoir area.

than that of the conversion to grassland and other land uses, which was the indirect impact of urbanization and submerged area which was the direct impact of TGP, the comparison of the area of cultivated land to other land types showed that the total area of farmland reverted to forest was greater than that of urbanization (Table 3). It was proved that reverting cultivated land to forest had a greater impact than urbanization on the lost cultivated land (Cao et al. 2013). In addition, the area converted to cultivated land was also significantly positively correlated with the area of cultivated land converted to built-up land (P<0.01), which may have been because of the occupation of cultivated land resulting from urbanization, forcing some farmers to reclaim new cultivated land.

There were different driving factors behind the cultivated land change during the different stages, and the factors during the later stage of the project were the most complicated. According to the cultivated land area loss caused by the driving factors (Table 3), the driving factors were ranked in order of importance as follows: reverting cultivated land to forest >> urbanization > construction of the TGP. Previous scholars have argued that urbanization was the main reason behind the cultivated land change in the reservoir area (Zhang et al. 2009). However, we found that the area change affected by returning cultivated land to forests during the later stage was far greater than the sum of the other driving forces between 1992 and 2015. The area of converted cultivated land greatly increased, and the center shift was most distinct during the later stage. Cultivated land was mainly transferred to forest during this period. In addition, as Table 4 shows, urbanization was the main driving factor during the early and operational stages of the project. The impact of the TGP on the change in cultivated land area was generally greater during the later stage than during the early and operational stages. The increase in the land area converted to cultivated land may be explained by the large demand for cultivated land by immigrants (Hwang et al. 2013), which was an indirect impact of the TGP, and to some extent, also an impact of accelerated urbanization (Cao et al. 2013). The trajectory of cultivated land change during the different stages was in line with reservoir construction and the regular pattern of cropland disturbance and demand (Li et al. 2018).

The impacts of cultivated land on forest conversion and the TGP gradually weakened over time, while the impacts of urbanization gradually increased. First, the magnitude and spatial distribution of cultivated land change may represent regional social development and urbanization. Studies have shown that in China (Tang and Di 2019), India (Tang and Di 2019), and the United States (Moroney and Castellano 2018), there is a positive correlation between cultivated land abandonment and urbanization. At the same time, the TA and MPS for cultivated land were in line with the urbanization trend (Song et al. 2016; Wang et al. 2016). The change in cultivated land showed that urbanization was a stronger driver than the TGP (Zhang et al. 2009). Second, cultivated land at slopes greater than 25° would ideally be converted to forest according to the cultivated-land-to-forest policy. After comparing the converted cultivated land to forest area between 2000 and 2015, the area of returned cultivated land gradually decreased. Therefore, the impact of cultivated land to forest conversion on the cultivated land change gradually decreased. Finally, the flooding and the immigration into the reservoir area as a result of the TGP ended in 2010 (Strehmel et al. 2016); thus, urbanization is expected to become the main driving force for cultivated land change in the future.

3 Conclusions

This study described the distribution and change patterns of cultivated land in the reservoir area using a landscape index, standard deviation analysis, a transfer matrix, and correlational analysis to identify the main driving forces behind the cultivated land change. The results showed that the cultivated land area decreased throughout the study period. It decreased the most (29.87 million ha) in the tail area but increased by 5.59 million ha in the central area. There were only 0.62 million ha of stable cultivated land during the period from 1992 to 2015. The head, central, and tail areas were 72,533, 0.18 million, and 0.37 million ha, respectively. It is known from the spatial distribution and the shift in the center of the cultivated land area that the distribution of cultivated land decreased in the north. Cultivated land use in the head and central areas of the reservoir also continued to grow. Cultivated land change across the different regions showed periodic characteristics and was most severe during the later stage of the project.

The main driving factors for cultivated land change differed between different stages. The area converted to cultivated land was significantly positively correlated with the area converted to built-up land, to grassland and other land use, and to submerged area ($P<0.01$). In addition, there was a significant positive correlation between the areas converted to cultivated land and urbanization ($P<0.01$). The lost cultivated land and the reversion of cultivated land to forest had a significant positive correlation ($P<0.05$). This showed that urbanization, the TGP, and the reversion of cultivated land to forest were the main driving forces for cultivated land change. The impacts of the TGP mainly occurred during the later stage of the project, and the affected areas were concentrated in the head and central areas of the reservoir. The impacts of reverting cultivated land to forest mainly occurred during the later stage of the project, and the affected areas were concentrated in the central area. Finally, the impacts of urbanization mainly occurred during the early and operational stages of the project, and the affected areas were concentrated in the tail area.

The main driving factors for cultivated land change in the different regions were also different. Sorted by the size of the area affected, they were as follows: reverting cultivated land to forest >> urbanization > TGP. The head area was mainly affected by the conversion of cultivated land to forest and the TGP. The central area was mainly affected by urbanization and the TGP. The tail area was mainly affected by urbanization.

Urbanization will become the main driving force behind cultivated land change in the reservoir area in the future. As cultivated land is expected to decrease, the following two suggestions are proposed from the perspective of sustainable development and cultivated land utilization. First, ecological agriculture should be promoted, and land production potential should be improved by introducing better seeds and enhancing the management efficiency of cultivated land. Second, the transfer of cultivated land management rights from smallholder farmers to large household plots should be encouraged, and moderate-scale agricultural operations should be promoted where conditions permit. This will compensate for the reduction in cultivated land resources and promote stability and prosperity for farmers in the reservoir area.

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