Spatio-temporal variation of agricultural land consolidation in China: case study of Huangshi, Hubei Province

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ABSTRACT

Land fragmentation and soil degradation are major barriers to agricultural production. Agricultural land consolidation (ALC) can effectively address these problems. A regional case study in Central China was used to analyze the spatial characteristics of the implemented ALC projects (ALCPs) from 2003 to 2010, and the planned ALCPs from 2011 to 2020. ALCPs were classified into basic farmland construction projects (BFCPs) and low-hilly land consolidation projects (LHLCPs). The spatial distribution of BFCPs and LHLCPs was presented on maps with a 1:10,000 scale. A comparative analysis showed that the landscape indices of the project areas varied significantly in different phases. The implemented BFCPs are more centralized in space than the implemented LHLCPs. The proportionality (p) was proposed to evaluate the rationality of ALC planning at the town level. Results showed an apparent imbalance of p values among different towns. Shape regularity and centrality are important criteria for selecting ALCPs at spatio-temporal level. The maps provide a patch-based overview of the distribution and aggregation of ALCPs from 2003 to 2020. The findings have implications on assessing rationality and time scheduling of ALCPs.

1. Introduction

China is urbanizing at an unprecedented rate. The percentage of urbanization increased from 17.9% to 52.6% between 1978 and 2012 (Bai, Shi, & Liu, 2014). Accelerated urbanization results in conflicts between newly built-up land demand and arable land protection (Liu, Zhang, et al., 2010; Long, 2014). Areas of arable land that have been converted for non-agricultural use are increasing with the growing demand for built-up land. The area per capita of arable land decreased from 0.106 ha in 1996 to 0.092 ha in 2010, which was less than 40% of the global average (Kong, Liu, Liu, Chen, & Liu, 2014). Irrational cultivation, including frequent tillage and overuse of fertilizers and pesticides, can cause several environmental problems, such as soil degradation, soil erosion, and groundwater pollution (Gong, Meng, Li, & Zhu, 2013; Liu, Wang, & Long, 2010). Shortage of arable land resources is the most significant challenge facing rural China’s development, and severe loss of valuable arable land has caught the attention of the central government (Kong, 2014; Lin & Ho, 2003).

Land consolidation (LC) is the most effective land management approach to solve land fragmentation and improve the fertility of arable land (Demetriou, Stillwell, & See, 2012; Kupidura, Luczewski, Home, & Kupidura, 2014; Pašakarnis & Maliene, 2010) and has been applied in many countries worldwide. LC can be classified into four major types: rural construction consolidation, unused land exploitation, waste land reclamation, and most importantly, agricultural land consolidation (ALC), which plays a key role in improving the quantity and quality of arable land. ALC projects (ALCPs) are generally classified into basic farmland construction projects (BFCPs) and low-hilly land consolidation projects (LHLCPs). BFCPs are the key projects in revitalizing resource-based cities in China. BFCPs build concentrated continuous arable land with supported infrastructure, stable and high yield, good ecological environment, and strong disaster resistance. LHLCPs are engineering measures to exploit land resources on low hills and gentle slopes as well as to extend arable land (Ma, Du, & Qian, 2012).

The Chinese government initiated statewide LC projects (LCPs) over a decade ago (Jiang, Wang, Yun, & Zhang, 2015). More than 115,000 LCPs in China were implemented with a total area of 61,300 km² from 2006 to 2010. The implementation resulted in an increased area of 20,800 km² of arable land, which exceeded the combined area of land damaged by disasters and occupied by urbanization during the same period (Zhang, Zhao, & Gu, 2014). However, China’s rapid advancement in LCPs has also resulted in a series of problems. Focusing more on quantity than quality of increased arable land is important in China although ALC primarily maintains the quantity and quality of arable land.
equilibrium of arable land. The quality of arable land varies greatly in different areas. The total quality of arable land is deteriorating but the total amount of arable land is balanced. Plenty of high-quality arable land has been converted into built-up land in the urbanization process. The supplementary arable land in ALC areas is relatively low in quality, which includes four aspects, namely, cultivation suitability, land productivity, economic benefits, and soil contaminating degree. Blind arrangement of ALCs is a remarkable reason for inefficient land consolidation. Some local governments and planners did not know how to arrange the ALCs because of their lack of perception of the global distribution of agricultural land and limited understanding of the spatial relationship between the implemented ALCs and planned ALCs before 2010.

The spatial distribution of ALCs reflects the land-use policy of the local government and characteristics of land resources. The ALCs, especially for BFCPs, are highly related to arable land in area. ALCs are easily selected in the early stages. With the increasing ALCs implemented from 2001 to 2010, the local governments and planners face more challenges in selecting ALCs for subsequent LC planning stages. Moreover, a new concept of overall land consolidation was proposed in China’s land consolidation planning (2011–2015), which required LCPs to plan regarding regional balance and land resource difference. The ALCs should be consistent with the land-use structure. Therefore, finding an effective way to evaluate the rationality of ALCs at the town level is necessary.

This study reveals the spatio-temporal variations in ALCs in Huangshi City, Hubei Province, China. A database of ALCs, including BFCPs and LHLCPs, was built based on the land-use map. Four phases, including 2003–2007, 2008–2010, 2011–2015, and 2016–2020, further clarify the spatial variation and landscape features of ALCs. The quantitative relationship between ALCs and agricultural land was analyzed in different towns to evaluate the proportionality of ALCs in Huangshi City. The visualization of ALCs in different types and stages can present intuitive information to identify the spatial relationship between implemented ALCs and planned ALCs, as well as the difference in quantity among different towns (see Main Map). This study attempts to assess the rationality of ALCs in quantity and space, and assist LC planners and designers in formulating appropriate time scheduling of ALCs.

### 2. Materials and methods

#### 2.1. Study area

Huangshi City is located in southeastern of Hubei Province (114°31′–115°30′ E, 29°30′–30°15′ S) and faces the Yangtze River in the northeast. Huangshi is a resource-based city with rich mineral resources and is a sub-center city of the Wuhan metropolitan area. Huangshi has 6 districts, 49 towns, and a population of 2.6 million. This city covers a total area of 4565 km², including 128,996 ha of arable land. The area per capita of arable land is 0.05 ha, which is half of the national average. The local government initiated organized ALCs in 2003 to protect the arable land. According to official statistics, 87 ALCs with an area of 25,812 ha were approved and implemented from 2003 to 2010. A total of 228 ALCs covering an area of 106,726 ha are scheduled to be implemented in the LC planning (2011–2020) of Huangshi.

#### 2.2. Data sources and processing

The primary data sources of ALCs include land-use data (scale of 1:10,000 for 2010), implemented LCP database (2003–2010), and LC planning (2011–2020) database, all of which were provided by the Huangshi Bureau of Land and Resources. The land-use data of Huangshi City were classified into 27 land-use types according to the Second China Land Census Classification Standard. These types are subject to three basic types: agricultural land, built-up land, and unused land. To highlight the main land consolidation types of ALCs and improve the recognition of land-use types, we retained the top-level classification of built-up land, the second level classification of agricultural land, and isolated water from unused land. Thus, seven land-use types were identified: arable land, orchard, forest, grassland, water, built-up land, and other land.

The ALCs were divided into different phases according to the time of approval. The BFCPs were divided into four phases: 2003–2007, 2008–2010, 2011–2015, and 2016–2020. However, the LHLCPs, which were proposed as a new land consolidation type by Hubei government in 2008, were divided into three phases: 2008–2010, 2011–2015, and 2016–2020. The database of ALCs was constructed using ESRI ArcGIS 10.

#### 2.3. Methods

Landscape metrics provide a quantitative description of a spatial landscape (Ramachandra, Aithal, & Sanna, 2012). The heterogeneity and integrity of landscape are both a cause and a consequence of arranging ALCs. Landscape indices were carefully selected to ensure that the metrics are relevant to the objectives of this study and not redundant (Wu, Jenerette, Buyanuyev, & Redman, 2011). Six indices (Table 1) were identified to provide a patch-based overview of the quantitative features of ALCs from 2003 to 2020.

The proportionality ($p$) of implemented and planned ALCs was calculated to clarify the relationship between ALCs and agricultural land at the town level. The $p$ is described by the following
area of BFCPs of town, \( p_B \) and \( p_L \) of ALCPs in 49 towns was calculated using Formulas (1) and (2). The proportionality values were classified into four levels (I, II, III and IV) using the same set of class intervals for simple interpretation (Table 2). The values of \( p_B \) and \( p_L \) were compared between the periods 2003–2010 and 2003–2020. An apparent imbalance of \( p_B \) values was found among the 49 towns. A total of 41 towns, accounting for 83.67%, belonged to Level I, and 21 of the towns did not implement any BFCP from 2003 to 2010. These towns were mainly located in the north of Huangshi, which is the site of downtown area. The agricultural land, especially arable land, was scarce in these towns. Among them, 19 towns have no arable land. The number of towns in Level I decreased to 22 from 41 by 2020, whereas the number of towns in Level II increased to 8 from 4, that in Level III increased to 11 from 1, and that in Level IV increased to 8 from 3. Correspondingly, the \( p_L \) values significantly increased during the same period because of the vigorous advance of land consolidation. It should be noted that the \( p_B \) of 11 towns (except for 19 towns without arable land) and the \( p_L \) of 19 towns (except for 26 towns without low-hilly land) were below Level III by 2020. These towns should be given more attention to arrange ALCPs in the future ALC planning.

The landscape characteristics of different phases are presented in Table 3. Class area (CA) and number of patches (NP) initially increased from 2003 to 2015 and decreased from 2016 to 2020 for both BFCPs and LHLCPs. The increase reflected the efforts of the local government to reinforce the ALC strength and scope in promoting agricultural production. However, the agricultural land resources were limited, and increasing ALCPs were implemented or planned from 2003 to 2015. The remaining agricultural land was also relatively decreasing and gradually more

| Level | BFCPs | LHLCPs |
|-------|-------|--------|
|       | NT    | T1     | T2     | NT    | T3     | T4     |
| I     | 0–0.25 | 41     | 22     | 0–0.25 | 46     | 37     |
| II    | 0.25–0.50 | 4     | 8      | 0.25–0.50 | 3     | 8      |
| III   | 0.50–0.75 | 1     | 11     | 0.50–0.75 | 0     | 1      |
| IV    | 0.75–1.00 | 3     | 8      | 0.75–1.00 | 0     | 3      |

Notes: NT = Number of towns; T1 = 2003–2010; T2 = 2003–2020; T3 = 2008–2010; T4 = 2008–2020.
difficult to implement because of spatial dispersion. The mean patch size (MPS) of the projects diminished over time for both BFCPs and LHLCPs. Thus, the concentrated area of agricultural land was more likely to be consolidated first. The selection of ALCPs could also be increasingly difficult over time. An apparent growth of landscape shape index (LSI) and mean proximity index (MPI) was found for BFCPs from 2003 to 2015. This growth indicated that the shape of BFCPs was becoming more complex and the spatial distance among BFCPs was becoming closer. The LSI for LHLCPs remained relatively constant. The variations of LSI were consistent with those of CA and NP for both BFCPs and LHLCPs. The decreasing value of aggregation index (AI) showed that the patches of ALC in the succeeding projects were not as compact they were previously. The landscape metric values of BFCPs were higher than those of LHLCPs in the corresponding phases. The higher value was caused by the difference of natural endowments between BFCPs and LHLCPs. BFCPs were mainly implemented to increase the production of arable land, and to improve conditions of agricultural production. The region with a high proportion of arable land will be prioritized for selecting BFCPs. However, one of the main purposes of implementing LHLCPs is to increase the amount of arable land. The landscape indices Pearson coefficients Significance

Table 3. Landscape metrics for BFCPs and LHLCPs in different phases.

| Indices | BFCPs | LHLCPs |
|---------|-------|--------|
| CA | 5230.62 | 1066.95 |
| NP | 64 | 109 |
| MPA | 81.73 | 21.41 |
| LSI | 10.59 | 39.59 |
| MPI | 965.69 | 638.31 |
| AI | 96.00 | 91.12 |

Table 4. Correlation analysis between CA and MPS, LSI, MPI, AI for implemented BFCPs from 2003 to 2010.

| Landscape indices | Pearson coefficients | Significance |
|-------------------|----------------------|--------------|
| MPS | -.398 | .388 |
| LSI | .959 | .001* |
| MPI | .742 | .056 |
| AI | -.776 | .040* |

*Significant at .05.

4. Conclusions

This study analyzes the spatial distribution of ALCPs from 2003 to 2020 in Huangshi City, China. The implemented and planned ALCPs were integrated into a unified database. Each ALCP is extracted and presented in a distribution map. The spatial relationship between BFCPs and LHLCPs is clearly visualized in different phases. The spatial distribution of ALCPs is highly uneven in different towns, which is closely related to the local conditions, including terrain and land-use structure. The comprehensive proportionality is proposed to evaluate the rationality of ALC planning at the town level. The results show that the proportionality improved significantly from 2011 to 2020. However, some towns are still below Level III. The ALC potential of these towns is large, and should be well organized in the next ALC planning. The landscape index analysis shows the rapid decrease of the MPS of ALCPs, which is undergoing a process of fragmentation, as well as irregularity, thereby increasing the difficulty of future site selection for ALCPs. ALC aims should be converted to adapt to this change. The government should aim to improve the quality of arable land by ALC, and not only increase the quantity of arable land.

The results also provide important information for planners and designers in scheduling ALCPs. First, the planned ALCPs are clear to the spatial range but do not consider the schedule for each ALCP from 2011 to 2020. Planners and designers should start with the easier
ALCPs before moving to the more difficult ones. The planned ALCPs adjacent to the implemented ALCPs are given priority in the planning periods for the sake of tract land consolidation. The spatial features of the implemented and planned ALCPs presented in this study are crucial to the planned ALCP scheduling. Second, the implementation process of LC planning is dynamic in China. A few ALCPs are predicted to be rearranged because of the changes of governmental land-use policy and the new requirements of agricultural development. Thus, the relevance shown in this study provides an important basis for ALCP adjustment. The proportionality difference also pointed out the key towns in the next ALC planning.

In summary, this study aids our understanding of the process and spatio-temporal features of ALC. The quality of ALCPs is the most important criterion to evaluate success. ALC is a complex process that involves an extensive project survey and engineering test, and is relatively easy for a single ALCP. Further research should pay more attention to the study of quality evaluation at the town level.

Software

The spatial distribution maps were drawn in ESRI ArcGIS 10. The relevance between quantitative characteristic and spatial feature was analyzed using SPSS 19. The landscape indices of the ALCPs were analyzed using Fragstats 4.2. The landscape changes of ALCPs were plotted using OrginPro 8.

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