Systematic spatial targeting of cultivated land consolidation with stakeholders to manage trade-offs between urbanization and food security in China

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Abstract: Over the past four decades, China has invested $298 billion in cultivated land consolidation (CLC), making a substantial contribution to increased agricultural production and enhanced food security despite rapid urban expansion and cultivated land encroachment. However, in the absence of a quantitative, spatial evaluation of CLC potential that engages local stakeholders including farmers, community, and decision-makers, the scope for systematic planning to guide and influence the prioritization, effectiveness, and efficiency of CLC for achieving enduring benefits for agricultural productivity and sustainability is limited. In this study, we used a knowledge co-production approach with spatial multi-criteria analysis (MCA) for evaluating CLC potential in Jiangsu Province and identifying priority areas with the participation of stakeholders. We identified key priority areas and considerations for ensuring CLC implementation for supporting the transition to more productive and sustainable agricultural systems including 7 priority types across 813 townships. 41.82 % of the areas were targeted for resource consolidation, 33.83 % for pattern consolidation, and 9.84 % for utilization consolidation, with the remaining 14.51% for combined consolidation based on multiple criteria. While 686 townships with low and very low CLC potential were incorporated into the CLC planning as protection and development priority types. These spatially explicit results can inform regional prioritization and targeting investment in CLC projects with a high level of buy-in from stakeholders. The methodology and findings of this study can inform innovation in systematic spatial planning with stakeholders for CLC across China and help manage the trade-offs between urbanization and food security.

Keywords: cultivated land consolidation; comprehensive zoning; food security; agricultural productivity; urbanization; China

1. Introduction

Cultivated land is a fundamental but limited resource vital for sustainable development (Foley et al., 2011). The efficient utilization and management of cultivated land underpins food security, rural livelihoods, economies, social security, and environmental integrity (Godfray et al., 2010). As the scale and intensity of human activities have continued to increase, demand for and pressure on land has boomed globally (Zuo et al., 2018). This is particularly evident in rapidly developing countries such as China where population growth and increasing socioeconomic development and urbanization have led to increased agri-food demand from declining arable land area (Wang et al., 2022). The ever-decreasing quantity and quality of cultivated land have threatened food security and posed severe challenges to sustainability (Huang et al., 2019). To effectively alleviate these pressures and improve the sustainability of agri-food production (see SDG 2.4 Sustainable food production and resilient agricultural practices), it is necessary to boost productivity on the limited amount of cultivated land to lessen the impact of competition from land-uses such as urbanization (Griggs et al., 2013; Gao and Bryan, 2017).

Cultivated land consolidation (CLC) plays a major role in creating more effective and efficient land use in many countries around the world (Janečková Molnárová et al., 2023), including China (Tang et al., 2019), Ethiopia (Teshome et al., 2016), Turkey (Tezcan et al., 2020), Cyprus (Demetriou et al., 2012), Czechia (Podhrázská et al., 2015), Poland and the Netherlands (Stańczuk-Gałwiaczek et al., 2018). China has extensively implemented CLC to create more favorable management conditions for agriculture by improving food production capacity, reducing land fragmentation, configuring an efficient spatial structure, and upgrading infrastructure to meet the increasing demand for food and meet food security objectives (Zhou et al., 2019). Over 53.33 million hectares of high-standard farmland in China had been improved via CLC by the end of 2020. This has led to increased grain productivity of 10 - 20% and on-farm cost savings of $1162.58 per hectare per year, on average (Duan et al., 2021; Lu, 2021; National Bureau of Statistics of China, 2021). However, competing demands for cultivated land and emerging trade-offs between urbanization and food security have increased the pressure on agricultural land. High-intensity cultivated land utilization is often accompanied by soil erosion, soil and water resource degradation and pollution, resource-use inefficiency, fragmentation, and a lack of coordinated infrastructure (Xie et al., 2020). To manage these complex challenges, CLC initially focused on increasing land quantity, focusing equally on increasing quantity and quality of farmland, and endeavoring to construct and protect basic farmland and compensating for the losses to urbanization (Zhou et al., 2020). More recently, CLC has also focused on enhancing the ecology of cultivated land to conserve natural resources, boost environmental carrying capacity, and improve land quality and efficiency (Asiama et al., 2017).

Quantifying CLC potential can provide a rational basis for land consolidation planning and the efficient targeting of improvement in cultivated land. CLC potential can be defined in terms of a set of functions and parameters that regulate the scaling of land resources and the configuration of land-use structure, intensity, infrastructure, and productive capacity (Ye et al., 2022). These elements can be quantified, mapped, and integrated into a spatial layer defining the priority of each parcel for land consolidation. Quantifying CLC potential aims to identify underlying areas with unfavorable agricultural conditions or barriers to production using spatially differentiated indicators of cultivated land (Wójcik-Leń et al., 2019). Areas with unfavorable conditions, such as lower resource endowment, land degradation, higher fragmentation, lack of rural infrastructure, and requiring road and drainage construction, have a higher potential for consolidation than other regions.

Quantifying CLC potential is a critical foundation for planning to improve unfavorable conditions, remove barriers to production, prioritize consolidation project implementation, and ensuring productive yet sustainable agricultural land use (Jiang et al., 2017). Studies have applied various qualitative and quantitative approaches for evaluating CLC potential, primarily focusing on the quality of cultivated land based on limiting factors. Some studies have calculated CLC potential as the gap between current and theoretical quality under climate, soil properties, and technical farming conditions (Brown et al., 2008; Tang et al., 2017). Other studies have assessed changes in factors related to productivity potential (Ye et al., 2022; Yuan et al., 2022), incorporating quality and quantity indices at different spatial scales to reflect the potential for agricultural production and supplement cultivated land (Gasparri et al., 2015; Ge et al., 2020; Hiironen and Riekkinen, 2016). Despite the development of various methods for investigating CLC potential, the formulation of CLC planning is often oversimplified into a single dimension or quantitative indicator (i.e., increasing farmland area or improving quality grades) and often ignores other key information such as land condition and environmental quality, making it hard to implement effective land consolidation. Incorporating a comprehensive suite of factors that fully consider the diverse and multi-faceted components to tailor the situation to local conditions is crucial for evaluating potential and developing appropriate planning for CLC (Han et al., 2021).

Effective decision-making needs to incorporate the views of stakeholders. Various participatory methods have been applied in studies to engage multiple stakeholders such as governments, professional organizations, local elites, and marginalized farmers across different levels to guide better CLC decision-making. Methods such as empirical surveys, field surveys, structured questionnaires, program-level and village-level interviews, and focus group discussions have been applied in CLC implementation. Participatory approaches have assessed multiple aspects including local needs (Pijanowski et al., 2022), social capital values (Tepnadze et al., 2022), potential conflicts between stakeholders (Demetriou et al., 2012), bottom-up participation (Wang et al., 2014, 2019), influence of local elites (Liu et al., 2016), and the attitudes and satisfaction of landowners (Lisec et al., 2014; Luo and Timothy, 2017). For example, Tezcan et al. (2020) involved the land valuation committee, academic staff, engineers, and local landowners in making land valuation more accurate for CLC and de Vries (2022) suggested that engaging stakeholders extended CLC knowledge and made planning more socially responsive and socially enabled. While these studies have demonstrated the value of knowledge co-production via public participation in CLC planning, implementation of these transdisciplinary approaches remains limited in planning, decision-making, and management of CLC in China, hindering the improvement of outcomes and satisfaction among multiple stakeholders. Integration of knowledge coproduction in decision-making and systematic spatial targeting to guide future planning is crucial for enhancing the effectiveness of CLC.

Spatial multi-criteria analysis (MCA) combines complex multidimensional data analysis with the direct involvement of stakeholders, considers multiple criteria, and integrates multiple layers of diverse spatial information for identifying priority areas (Raaijmakers et al., 2008; Li et al., 2020). Previous research has integrated social, economic, and political considerations by applying spatial MCA to identify priority areas for bird conservation (Hou et al., 2022), soil-water conservation areas (Ahmed et al., 2023), ecological conservation and restoration (Chen et al., 2023), flood risk mitigation (Rehman et al., 2022), and conservation planning (Brum et al., 2017). Recent studies have demonstrated the potential of using spatial MCA systematically and transparently to facilitate planning more efficient, acceptable, and equitable CLC. For example, Tomić et al. (2018) developed a land consolidation suitability index to specify priority areas for CLC, increasing transparency and effectiveness for decision-making with input from project participants in Croatia. Janus and Taszakowski (2018) created a weighted synthetic indicator that can be modified to accommodate changing criteria or policies to evaluate the urgency for implementing land consolidation in Poland. Pašakarnis et al. (2021) applied a multi-criteria decision analysis framework to identify and prioritize regions at municipal and project area levels for efficient management of land consolidation in Lithuania. These studies have demonstrated the potential of spatial MCA in a participatory context with stakeholder engagement to identify criteria and elicit their relative importance for prioritizing CLC in China.

In this study, we used a participatory process to systematically prioritize CLC potential via spatial MCA with stakeholders and identify priority areas for implementing CLC to manage the trade-offs between urbanization and food security. We focused on Jiangsu province, China, a highly productive agricultural region which is also subject to rapid urbanization. The main objectives of this paper are to propose a spatial MCA method involving stakeholder participation and knowledge co-production to identify important criteria and priority areas for CLC potential, and clarify the types of priority areas to propose consolidation pathways and strategies. This study provides a reference for making systematic planning of CLC more transparent and inclusive for stakeholders to guide prioritization and the effectiveness and efficiency of project allocation and investments. It establishes a scientific foundation for involving diverse perspectives of stakeholders via the spatial MCA analysis tool that enhance CLC planning and decision-making processes.

2. Methods

2.1. Study area

Jiangsu Province, one of China's most developed provinces, is located in the central region of China's east coast (Fig. 1). The region covers 10.72 million hectares, including 13 cities and is home to 80.51 million people. Jiangsu ranks fifth in food production in China, with 43% of its land area arable. Equivalent to 0.06 hectares per capita, cropland availability is below the national average of 0.08 hectares. Agricultural development has lagged behind its economic growth due to high fragmentation, limited reserves of cultivated land resources, and competition for land between urban development, agricultural production, and ecological conservation.

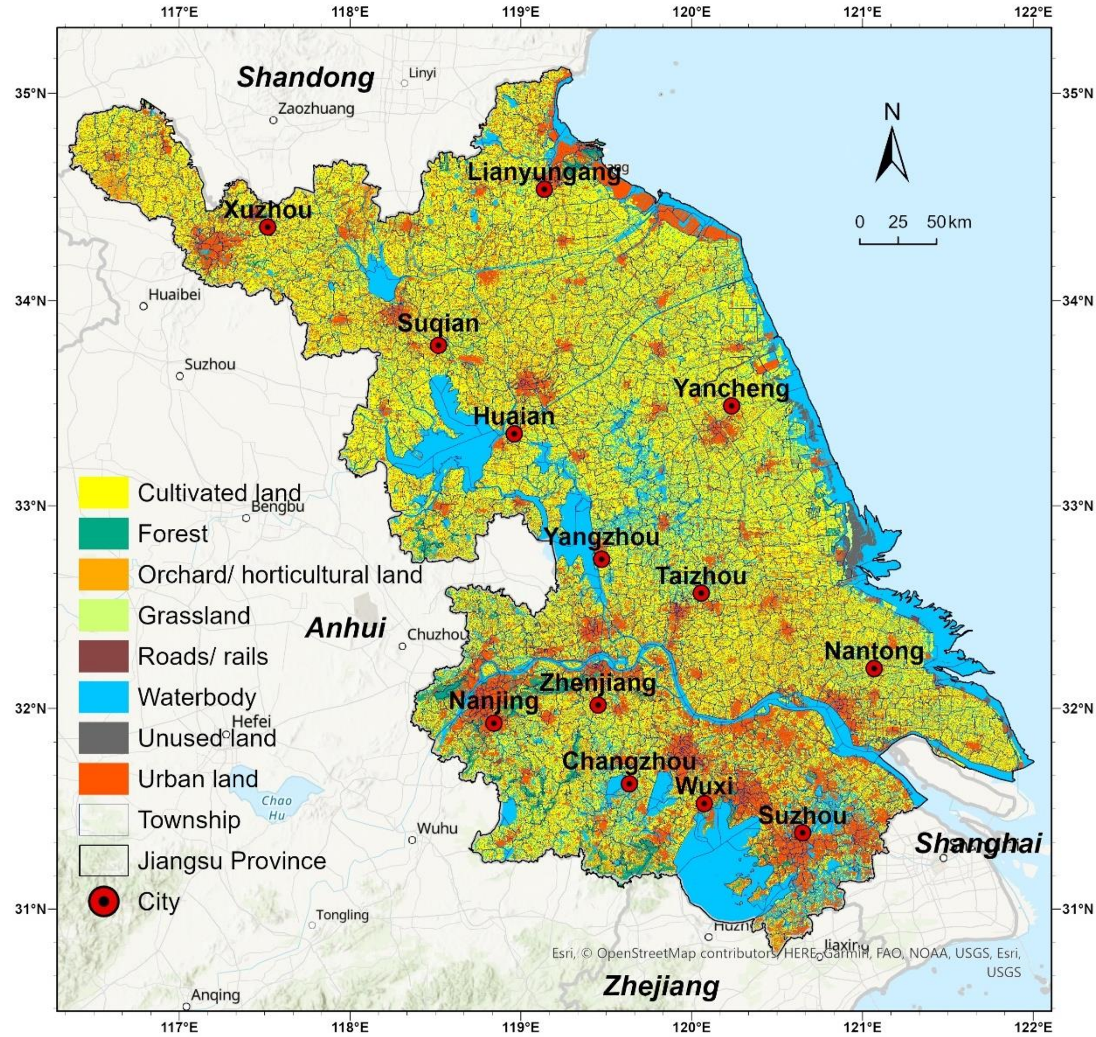


Fig. 1. Spatial distribution of land cover in the study area. The basemaps were obtained for ESRI at ArcGIS Online Basemaps (Esri, 2013).

2.2. Data sources

In this study, the 1499 township-level administrative divisions of Jiangsu in 2017 were adopted as the basic spatial administrative unit. We integrated multiple datasets, including land use, satellite remote sensing, and socioeconomic data harmonized at 30 m × 30 m spatial resolution (Table 1). Maps were created and presented using ArcGIS Pro 2.9.0.

Table 1. Description of data sources used in this study.

Data Type	Data source	Data description
Land use data	Second National Land Use Change Survey of Jiangsu Province in 2017	1:10000 vector
Satellite remote sensing images	MOD13Q1 of 2001-2017 from NASA (https://search.earthdata.nasa.gov/)	250 m×250 m, 16 d raster
	MOD09A1 of 2001-2017 from NASA (https://search.earthdata.nasa.gov/)	500 m×500 m, 8 d raster
Cultivated land quality grade data	Agricultural land gradation by the former Ministry of Land and Resources	vector 1:500,000
Exploitation and utilization data of reserved land resources for cultivation	National Survey of Cultivated Land Reserves	1:10,000 vector
Rural settlements and administrative villages data	Resource and Environment Science and Data Center of the Chinese Academy of Sciences (http://www.resdc.cn/)	1:10,000 vector
Transport infrastructure data and water conservancy infrastructure data	Second National Land Use Change Survey	1:10,000 vector
Water resource data	The Water Resources Bulletin of Jiangsu Province	Statistics The basic unit is the county
Socioeconomic data	The Jiangsu Statistical Yearbook	Statistics The basic unit is the county

2.3. The participatory spatial MCA framework

A systematic evaluation of CLC potential identifies priority areas for addressing cultivated land issues around declining quality, ecological deterioration, boosting productive capacity, and decreasing fragmentation is essential. We drew on previous studies (Janus and Taszakowski, 2018; Wójcik-Leń et al., 2019; Pašakarnis et al., 2021) in establishing a participatory spatial MCA framework (Malczewski, 1999; Pacetti et al., 2022; Trialfhianty et al., 2022) to calculate CLC potential and identify priority areas with local stakeholders for CLC in Jiangsu Province (Fig. 2). First, to determine the criteria and structure of the framework for CLC, we undertook a comprehensive review of previous studies and conducted surveys and workshops with stakeholders. Surveys were conducted with representatives including small-scale local farmers, large-scale grain farmers, government officials, and experts. The results were qualitatively interpreted and integrated to perform pairwise comparisons and calculate the weights for the decision criteria using Analytica Hierarchy Process (AHP) (Saaty, 1977). Next, we gathered spatial data to present each criterion and used the weighted spatial MCA method of CLC potential to calculate and map the spatial distribution of priority areas. We then used the results to develop an integrated and comprehensive CLC potential index for identifying the priority areas aggregated to three main criteria. Finally, we analyzed and defined types of priority areas for CLC planning to determine appropriate management pathways to manage the trade-offs between urbanization and food security in this study area.

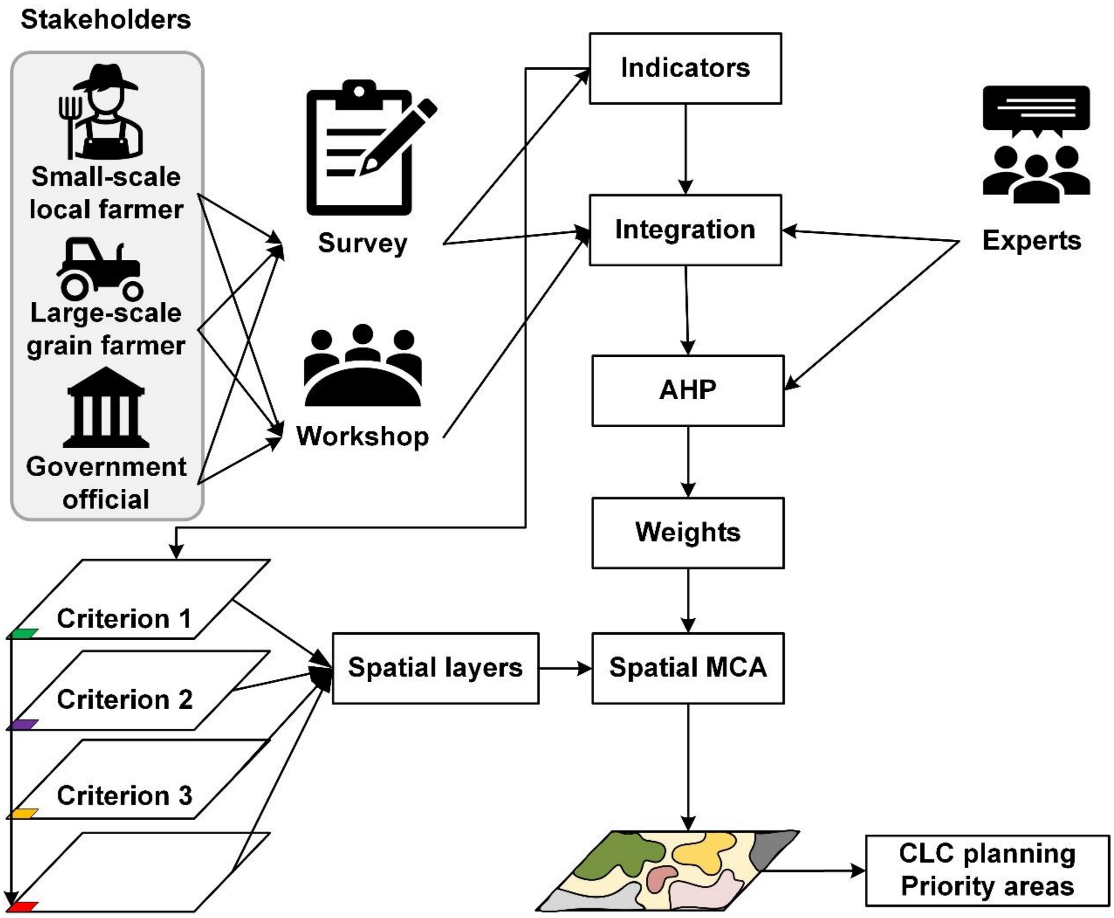


Fig. 2. Spatial multi-criteria analysis framework of cultivated land consolidation.

2.4. Evaluation methods for CLC potential

2.4.1. Defining the criteria

Defining the criteria for evaluation CLC potential is a key requirement for the spatial MCA approach by applying experts and focus group discussions. We established three criteria for cultivated land, each of which incorporates four sub-criteria (Table 2 & Supplementary Table A1). Criteria for Resource Condition describe the physical and environment factors that influence the productivity and sustainability of cultivated land, including parcel, climate, and soil property constraints and related factors and interactions. The Spatial Pattern criteria cover the distribution and the interaction of cultivated land with infrastructures and resources suitable for primary production. Criteria for Land Utilization emphasized the control of the productive space to achieve maximum synergy between production and ecological functions. Following data accessibility and statistical consistency principles, criteria with various units and scales were standardized for each criterion, transforming the original scale into a dimensionless scale between 0 and 1, which makes the potentials among different indicators comparable in each criterion.

Table 2. Evaluation criteria for cultivated land consolidation potential.

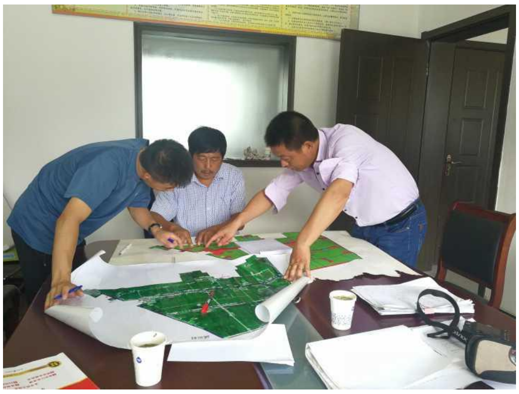
Criteria	Sub-criteria	Description	Attribute
Resource condition	Cultivated land quality (LQ)	The suitability and productivity of cultivated land for growing crops.	-
	Paddy field rate (PF)	The proportion of paddy field area to the total cultivated land area.	+
	Cultivated land protection rate (PR)	The extent of cultivated land is being protected from degradation or conversion to other land uses.	+
	Water-soil compatibility rate (WS)	The compatibility or suitability of the water resources available for agriculture and the soil conditions in a particular area.	+
Spatial pattern	Cultivated land fragmentation (LF)	The degree of cultivated land is divided into smaller, non-contiguous plots or fields.	-
	Cultivated land size rate (SR)	The proportion of cultivated land that falls within a large-scale for agricultural operations.	+
	Agricultural accessibility (AA)	The level of convenience and accessibility for farmers conducting agricultural activities.	+
	Infrastructure completeness (IC)	The level of development and availability of infrastructure of cultivated land.	+
Land utilization	Cultivated land productivity (LP)	The ability of the cultivated land to produce crops and support agriculture.	+
	Multiple-crop index (MC)	The diversity and intensity of cultivated land use for assessing the overall productivity and efficiency of agriculture.	+
	Habitat quality (HQ)	The suitability of the agricultural environment for supporting the survival, growth, and reproduction of species.	+
	Reserved resource development index (RR)	The extent of land reserve resources that can be developed and used for cultivated land use.	+

2.4.2. Weighting the criteria

We conducted a workshop containing 17 participants to organize the on-site investigation of CLC projects and conduct a project symposium (Fig. 3 & 4). This workshop was designed to establish a shared understanding of the objectives and methods of the CLC survey, as well as the roles and responsibility of different stakeholders. This approach allowed participants to share their expertise and insights, identify potential challenges and opportunities for CLC. This collaborative process enabled a valuable and comprehensive approach to develop more effective and sustainable strategies for CLC.

(a) Workshop for CLC

(b). Survey with government officials



(c). Survey with large-scale grain farmer

(d). Survey with small-scale local farmers

Fig. 3. Workshops and surveys with stakeholders planning for cultivated land consolidation in Jiangsu.

(a) Cultivated land patches before CLC

(b). Cultivated land patches after leveling

(c). Cultivated land fragmentation before CLC

(d). Cultivated land large-scale planting after CLC

(e). Ditch, channel, and road before CLC

(f). Irrigation ditches and channels, road after CLC

(g). Farmland before CLC

(h). High-standard farmland after CLC

Fig. 4. On-site investigation of cultivated land consolidation projects in Jiangsu.

We designed three types of paper-based questionnaires and interviews targeting the relevant stakeholders to provide a comprehensive and contextualized evaluation of the effectiveness and efficiency of CLC (Table 3 & Supplementary C. Questionnaire). First, basic information was collected from the government officials, gathering information on the overall layout, construction type, and investment in CLC projects. Second, respondents were interviewed about their experience with positive and negative impacts of CLC and requirements of consolidation measures. Third, we also collected detailed information about the management of large-scale grain farmers and small-scale local farmers. Finally, participants were asked about the other issues around the planning, design, and construction process of CLC, including the amount of comprehensive planning, unreasonable design, inadequate compensation, and management mechanisms.

Table 3. List of questions used in the interviews for cultivated land consolidation.

Q1: What is the current status of land use in this area? What are the issues and challenges?
Q2: What is the purpose of cultivated land consolidation? Does it align with local development planning and strategies?
Q3: Who are the participants in the land consolidation process? What are the attitudes and opinions on cultivated land consolidation?
Q4: What are the potential impacts of land consolidation on the local villages and environment, and what measures can be taken to reduce or avoid negative impacts?
Q5: What are the costs and benefits of cultivated land consolidation, and how about the long-term and short-term economic, social, and environmental impacts?

Overall, the results of the workshop and surveys can be used to develop a weighting scheme that incorporates the views and preferences of all stakeholders, and that reflects the relative importance of each criterion from their unique perspective. We collected 40 valid questionnaire responses from local stakeholders in Jiangsu (Table 4). We constructed a pairwise comparison matrix for each criterion and sub-criterion based on stakeholders' perceived importance of CLC to assign weights independently. The collected data from stakeholders were converted into the relative importance of the comparison criteria using a scale of evaluation ranging from 1 to 9 (Saaty, 1977; Drobne and Lisec, 2009; Trialfhianty et al., 2022), where 1 represented equal importance, and 9 represented extreme importance (Supplementary Table B1). After completing the pairwise comparison process, group discussions were held to share weights and identify the discrepancies or inconsistencies to reach a consensus on the final weights. We determined the final weights and the ratings to each criterion and sub-criterion that were calculated by taking the average of the weights assigned and then normalized and calculated the principal eigenvector of the pairwise comparison matrix. The weights of the criteria and sub-criteria was combined and determined using AHP Online System (Goepel, 2018). To ensure consistency, the overall consistency ratio (CR) was investigated based on the eigenvalue of the matrix and consistency index (CI), and sensitivity analysis was performed to measure the effect of each criterion.

$$CR = \frac{CI}{RI} \quad (1)$$

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (2)$$

Where, *CR* is the consistency ratio, *CI* is the consistency index, *RI* is the random index, λ_{max} is the maximal eigenvalue of the matrix, and n is the number of selected indicators. In this case, when n= 3, RI= 0.58, and when n= 4, RI= 0.89.

Table 4. Details of surveys.

Survey participants	Sample size	Survey method	Purpose
Government officials	6	Focus group discussion and questionnaires	To gather information on project progress and outcomes and providing insights for decision-making and policy development of CLC
Large-scale grain farmers	12	Interviews and questionnaires	To understand needs and preferences in terms of CLC
Small-scale local farmers	22	Interviews and questionnaires	To identify potential barriers and gain the farmers views of CLC

2.4.2. Calculating CLC potential

The value of CLC potential was determined by the difference between the current and optimal value of indicators based on local circumstances to avoid overestimation and minimize underestimation. Given the similar agricultural development and context, we adopted agricultural zoning of Jiangsu to determine the optimal value using the average ± standard deviation with consistent geomorphological conditions, soil types, hydrological characteristics, and vegetation types (Tang et al., 2017). The calculation method of $CLCP_i$ is as follows:

$$CLCP_i = \begin{cases} CLCP_i' - CLCP_\delta\,, & \text{if negative} \\ CLCP_\delta - CLCP_i'\,, & \text{if positive} \end{cases} \quad CL \in \{R, P, U\} \quad (3)$$

where $CLCP_i$ denotes the consolidation potential of sub-criteria i; $CLCP_i{}'$ represents the current potential; $CLCP_\delta$ indicates the optimal consolidation potential; i reflects sub-criteria ($i = LQ, \ldots, RR$). *R* represents the resource criteria, *P* indicates the pattern criteria, and *U* denotes the utilization criteria.

2.4.3. Identification priority areas

Dividing priority areas refers to prioritizing consolidation activities based on feasibility of CLC potential. We used spatial MCA framework to create the resource improvement consolidation potential (RCP), the pattern optimization consolidation potential (PCP), and the utilization enhancement consolidation potential (UCP) of cultivated land. We aggregated three criteria to calculate comprehensive CLC potential (CLCP), mapping with the equal interval method into five potential levels: very low (0-0.2), low (0.2-0.4), medium (0.4-0.6), high (0.6-0.8), and very high (0.8-1). Those townships with poor conditions classified as high priority consistently and significantly scored higher in multi-criteria exhibited the strong potential to improve and enhance their agricultural conditions within more effective consolidation projects than other regions. We summarized the characteristics of each priority area to determine the greatest priority type for CLC. Stratifying priority types to optimize the allocation of cultivated land and concentrate efforts on CLC implementation that are more likely to yield desirable outcomes. The calculation method of $CLCP$ is as follows:

$$RCP = \sum_{i}^{n}(R_i \times RCP_i) \tag{4}$$

$$PCP = \sum_{i}^{n}(P_i \times PCP_i) \tag{5}$$

$$UCP = \sum_{i}^{n}(U_i \times UCP_i) \tag{6}$$

$$CLCP = \alpha \times RCP + \beta \times PCP + \gamma \times UCP \tag{7}$$

where RCP represents the resource improvement consolidation potential, PCP indicates the pattern optimization potential; UCP denotes the utilization enhancement consolidation potential; R_i, P_i, and U_i are the weights of evaluation index i in the resource, pattern, and utilization criteria, respectively; α, β, γ are the weights of RCP, PCP, and UCP, respectively.

3. Results

3.1. Criteria weights within the spatial MCA framework

All results less than the CR value of 0.1 (10%) were within the acceptable range and the optimal consistency among the criteria (Supplementary Table B1). There is low potential variability in the importance or priority of different criteria or sub-criteria due to weights changes. Cultivated land quality ($\Delta w_+ = 5.1\%$ to $\Delta w_- = 5.8\%$) and cultivated land fragmentation ($\Delta w_+ = 0.8\%$ and $\Delta w_- = 0.6\%$) gained the highest and lowest weight uncertainty, respectively. Uncertainty ranges were generally higher for resource and pattern criteria than for utilization criteria. The resource criteria played an important role in identifying CLC potential, weighted 0.54, while 0.30 for pattern criteria and 0.16 for utilization criteria (Fig. 5). The results demonstrate that the highest priority was given to resource criteria over other criteria in identifying priority areas for CLC when developing policies and projects, as indicated by the highest weights assigned to those criteria. The resource criteria prioritized the significance of cultivated land quality, indicating that stakeholders perceived the important role of cultivated land quality as the natural foundation for agricultural production. The cultivated land size ratio received the highest weight among pattern criteria, while cultivated land fragmentation with the lowest weight since the size ratio was a critical factor for large-scale grain farmers to manage large-scale operations and for small-scale local farmers to transfer land. The utilization criteria revealed that cultivated land productivity held higher significance, indicating stakeholders' recognition of its crucial role in improving agricultural production and optimizing land use.

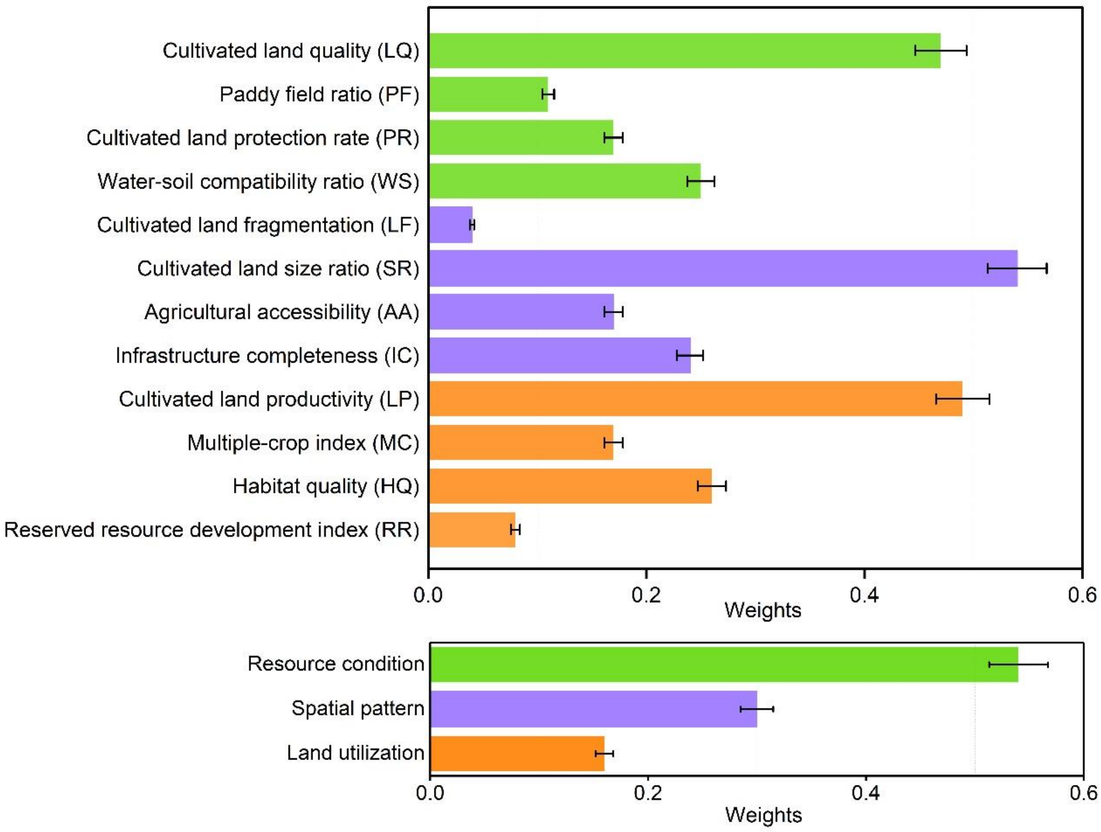


Fig. 5. Weights for criteria and sub-criteria in spatial MCA framework.

3.2. The spatial pattern of CLC potential

The spatial distribution of CLC potential as represented by the 12 sub-criteria is presented in Fig.6 and Table 5. Nearly 69.07% of the total cultivated land area needs to improve habitat quality, and 64.67% requires enhancement of infrastructure completeness, followed by increasing fields scale (53.31%), improving cultivated land quality (47.21%), and improvement in water-soil compatibility (39.63%). We found that agricultural accessibility in Jiangsu was favorable, with a high degree of road accessibility and road network coverage.

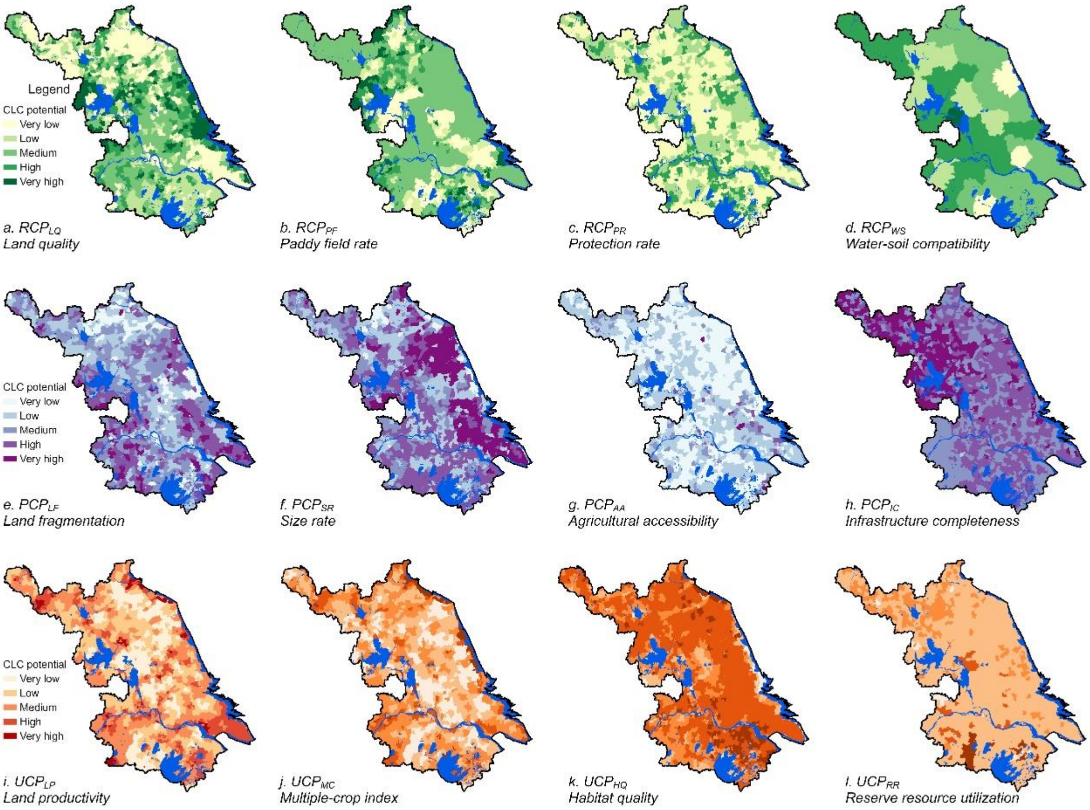


Fig. 6. Spatial distribution of sub-criteria cultivated land consolidation potential.

Table 5. Basic statistics results of cultivated land consolidation potential

Criteria potential	Sub-criteria potential	Indicators	Very low	Low	Medium	High	Very high
RCP		Number of townships	247	241	467	350	224
		Cultivated land (%)	17.21	20.85	35.32	20.98	5.65
	RCP-LQ	Number of townships	430	317	405	213	161
		Cultivated land (%)	0.07	17.99	23.98	17.58	29.63
	RCP-PF	Number of townships	185	147	906	146	115
		Cultivated land (%)	15.78	10.62	59.29	8.16	6.15
	RCP-PR	Number of townships	234	346	549	164	206
		Cultivated land (%)	18.34	36.33	32.35	8.78	3.97
	RCP-WS	Number of townships	63	259	609	546	22
		Cultivated land (%)	6.28	17.28	36.80	38.53	1.10
PCP		Number of townships	64	649	747	36	3
		Cultivated land (%)	3.92	37.00	55.19	3.66	0.23
	PCP-LF	Number of townships	133	387	591	303	85
		Cultivated land (%)	10.31	28.82	31.51	23.99	5.38
	PCP-SR	Number of townships	55	591	233	398	222
		Cultivated land (%)	2.86	23.44	20.39	31.24	22.07
	PCP-FC	Number of townships	674	683	117	21	4
		Cultivated land (%)	49.65	41.46	7.18	1.31	0.41
	PCP-IC	Number of townships	0	3	583	625	288
		Cultivated land (%)	0	0.34	33.99	40.01	24.66
UCP		Number of townships	34	752	471	197	45
		Cultivated land (%)	1.23	67.66	27.69	3.24	0.18
	UCP-LP	Number of townships	208	377	554	248	112
		Cultivated land (%)	21.53	36.53	31.65	9.49	0.80
	UCP-MC	Number of townships	236	413	513	237	100
		Cultivated land (%)	23.66	39.07	29.57	6.89	0.82
	UCP-HQ	Number of townships	54	121	397	756	171
		Cultivated land (%)	0.39	6.12	24.42	64.90	4.17
	UCP-RR	Number of townships	13	1250	174	32	30
		Cultivated land (%)	1.19	79.44	14.70	2.99	1.69

We found that 592 townships with high and very high RCP were distributed in southern and northern Jiangsu, representing uneven and relatively poor natural resource endowment and interactions between urbanization and food security significantly impacted cultivated land quality and water-soil compatibility (Fig. 7). 39 townships were identified with high and very high PCP in central and southeastern Jiangsu. Despite well-equipped road connectivity for agricultural production, there were relatively few areas of cultivated land suitable for large-scale operations with high land fragmentation. We also found that 242 townships were assigned as high and very high UCP. The environment of cultivated land had received insufficient attention during agricultural production with relatively low habitat quality in Jiangsu. These results highlighted the importance of implementing CLC in areas with high and very high potential to strengthen productivity, stability, and sustainability of cultivated land.

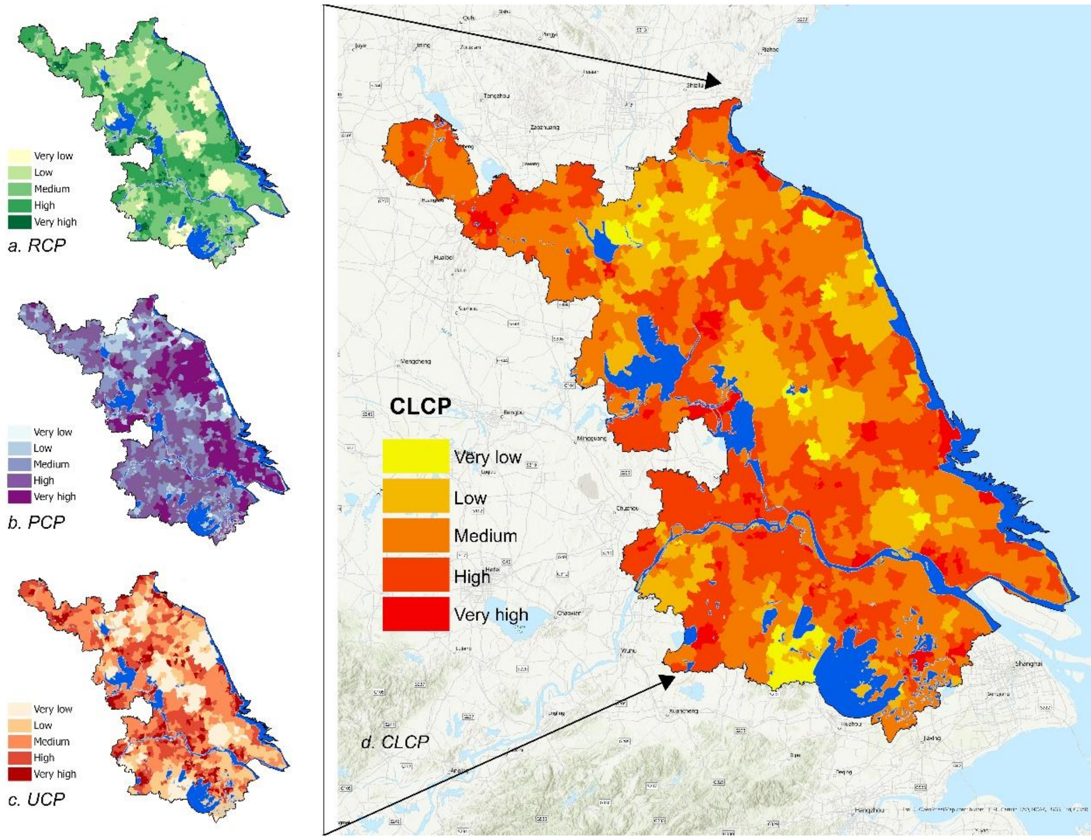


Fig. 7. Spatial distribution of criteria and comprehensive cultivated land consolidation potential.

The comprehensive CLC potential was created by combining RCP, PCP and UCP derived from the three criteria (Fig. 7). We found the identified issues were consistent with the concerns expressed by stakeholders during the workshop and survey. The higher CLCP values corresponded with greater urgency for CLC. The results indicate that almost a third of Jiangsu has unfavorable natural and production conditions (35.96%), which were considered priorities. The high and very high levels of CLCP have exhibited in cases of degradation, fragmentation, and loss of habitats across Jiangsu, and contributed to broader impacts across the other aspects of productivity and sustainability.

3.3. Priority zoning for CLC

We identified five priority zones based on overall potential and demonstrated in Fig.8. These high and very high priority areas, comprising the high and very high priority consolidation zones, cover 553 southern and central Jiangsu townships, such as Hailing, Gangzha, Kunshan and Lishui districts. Priority zones for CLC implementation in Jiangsu can play a significant role in returning to favorable production and can contribute to consolidation targets more generally, such as the protection, conservation, and restoration of resource, pattern, and utilization conditions of cultivated land. These zones have substantial potential to reduce degradation and fragmentation, and benefit from the multitude of co-benefits from CLC. Constructing infrastructure enhances the conditions for agriculture, improves the quality of land, and prevents loss of soil and nutrients via erosion. This results in increased resilience of crop diversity, yield stability, and sustainability, and promotes biodiversity, all with flow-on benefits to the effectiveness and efficiency of CLC. The low and very low priority areas like Muyang and Sihong counties were primarily focused on protecting cultivated land to maximize the sustainability and productivity and ensure efficient agricultural production.

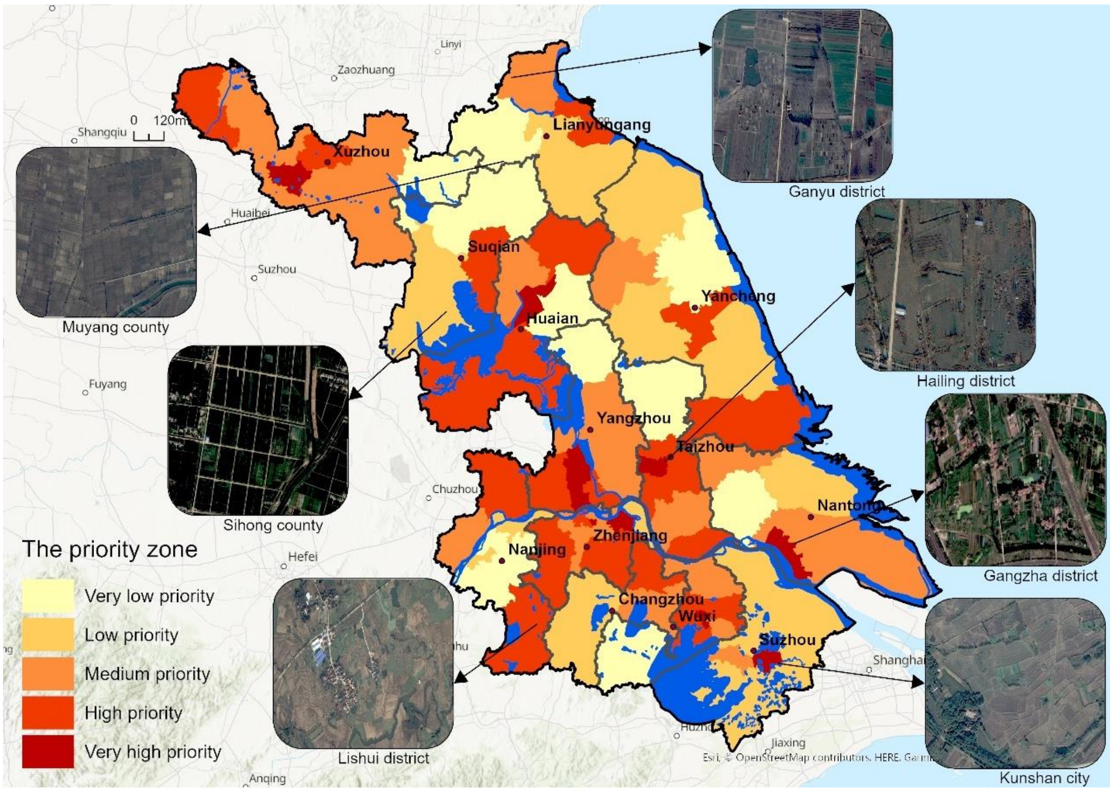


Fig. 8. Spatial characteristics priority zone and samples for cultivated land consolidation (Google Earth, 2017).

3.4. The priority type for CLC

Our study identified 9 key priority types of CLC based on multiple criteria to guide the allocation of projects and investments (Fig. 9). Of the total townships assessed, 813 (54.23%) were categorized into the 7 priority consolidation types, mainly concentrated in southern and coastal regions, with dispersed clustering in northern regions. 85.49% were designed for independent consolidation types focused on single criteria, either improved resource condition, optimized pattern, or enhanced utilization. 10.57% were allocated for integrated consolidation types with two criteria, while 3.94% were identified for comprehensive consolidation types encompassing three criteria. For instance, 340 townships were prioritized for resource consolidation, aiming to enhance resource conditions such as quality improvement, conversion of dryland to paddy fields, and construction of permanent farmland for improved production stability. 32 townships were targeted for comprehensive consolidation with poor conditions resulting from construction and human activities, aiming to alleviate fragmentation, promote conservation-intensive land use, and enhance the agricultural environment such as soil health. Our study revealed that the remaining 686 townships (45.77%) were classified into 2 priority types for high-quality protection and development, with low to very low potential. This included 95 townships where protecting high-quality cultivated land and conserving cultivated land reserves, and 591 townships where efficient agriculture production levels should be maintained.

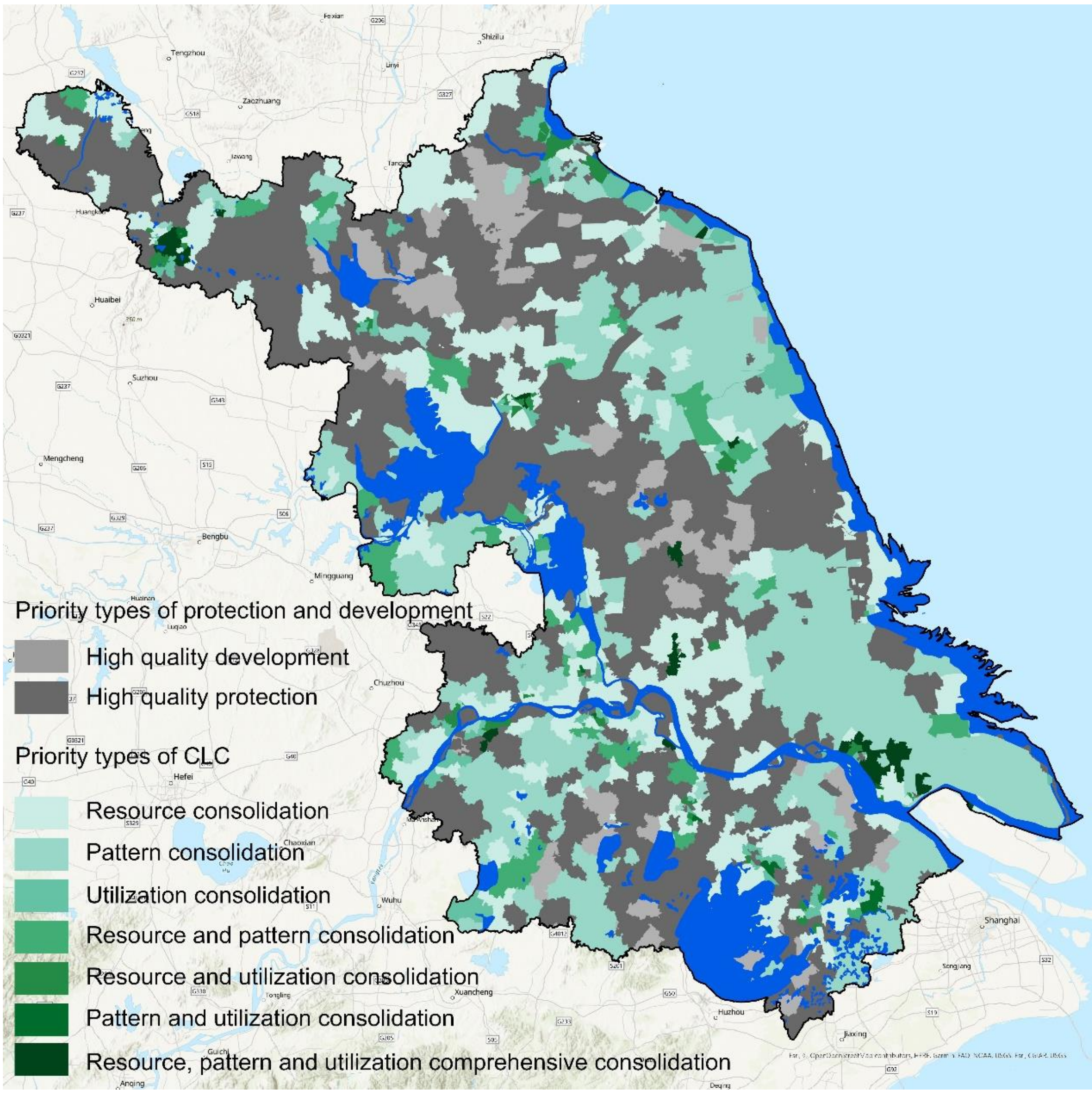


Fig. 9. The priority types for cultivated land consolidation.

4. Discussion

We have presented a quantitative and integrated evaluation of CLC potential using a spatial MCA framework involving the participation of stakeholders. The significant contribution of this study is that it explored the possibilities of involving stakeholders to support the CLC decision-making process in terms of increased effectiveness, efficiency, and transparency via knowledge co-production between experts and stakeholders, enabling the evaluation of CLC potential evaluation and identification of priority areas (Tezcan et al., 2020). Despite the evaluation of CLC potential and increasing research on land consolidation, methods of incorporating stakeholders' perspectives into CLC decision-making process are still poorly developed. Our study demonstrates the use of better data and decision support tools to improve management decisions, productivity, and environmental stewardship. Our findings have important implications for promoting CLC planning by analysis of potential challenges and opportunities.

4.1. Involving stakeholders to enhance the evaluation of CLC potential

Systematic evaluation using resource, pattern, and utilization criteria among townships in Jiangsu is a prerequisite for efficient and effective CLC implementation. As illustrated through this paper, small-size local farmers, large-scale gain farmers, and government officials expressed a readiness for public engagement, which created favorable conditions for knowledge co-production. The participatory ability, opportunity and incentive of stakeholders were strongly associated with CLC efficiency and effectiveness (Wang et al., 2019). Government officials possess a high degree of legitimacy, authority, and urgency to guide participation rights, procedures, and ranges and further incentivize farmers by establishing reasonable compensation standards (Liu et al., 2016). Farmers, as the ultimate beneficiaries of CLC, possess an intimate connection to the land and local knowledge necessary to address issues they face, ought to be the principal participants and decision-makers (Luo and Timothy, 2017).

We suggest that the relationships developed among stakeholders will sustainably serve future CLC development. Priority areas for CLC that support sustainable agriculture included the improvement of resource condition, production pattern, and utilization. Regarding the priority zones and types, we found that maximize favorable criteria to ensure food security while minimizing the occupation of cultivated land by construction and threats of urbanization. Targeted policy and management in these regions could further coordinate interactions between food production and urbanization, and ensure sustainable utilization of limited cultivated land. Such actions through CLC practices include capturing the interests of stakeholders, soil conservation measures to improve soil health and productivity, alleviating fragmentation to reduce transaction costs associated with land transfer, and facilitating transportation and irrigation system development. Our study underscores the significance of a comprehensive and systematic CLC planning strategy grounded on CLC potential, thereby facilitating the analysis of spatial consolidation and restoration and supporting the planning for CLC.

Current research suggests incorporating perspectives and considerations of stakeholders in CLC can be key determinants of their success (Podhrázská et al., 2015; Wang et al., 2019; de Vries, 2022). Here, we used workshops and surveys but much more work remains to be done to establish broader participatory methods to ensure that farmers have the ability and access to participate in the CLC planning process. Prioritizing knowledge co-production and participatory engagement with local stakeholders, involving diverse perspectives, expertise, and criteria, and providing relevant information with feedback and input about CLC, can build trust and support for both stakeholders and decision-makers (Zang et al., 2021). Integrating natural, socio-economic, and ecological considerations in a transparent decision-making process creates more sustainable and equitable outcomes to increase acceptance and feasibility of CLC. These tactics with inclusive and advanced technologies such as spatial MCA should be developed further and deployed using stakeholder-based and participatory approaches to ensure their effectiveness and acceptance, leading to a more sustainable and resilient land-use and food system.

4.2. Policy and stakeholder implications for land consolidation planning

Systematic spatial targeting of CLC planning is a thorough and thoughtful process used to gather input from relevant stakeholders and experts to inform decision-making in the local context. However, the CLC projects in China have predominantly been characterized by a top-down approach dominated by government planners, experts, and local managers (Jiang et al., 2022), resulting in top-down land consolidation strategies prioritizing administrative efficiency over farming efficiency (Tang et al., 2012). Since CLC was first applied in the 1990s, great progress has been made in reducing land fragmentation and promoting land-use sustainability in China (Long et al., 2012; Zhou et al., 2020). The practices of CLC potential in China include (a) increasing cultivated land area, (b) emphasizing the maximum area obtained through land development, arrangement, reclamation, and combination of fragmented land, and (c) improving cultivated land quality. Despite surveys for current land use, ownership, use rights, and public opinion, there is a lack of inclusive and participatory decision-making involving marginalized groups like local farmers, landholders, and communities, overlooking critical factors influencing consolidation efficiency and may not be optimal for all stakeholders involved.

Our findings indicate that better integrating stakeholders to address land quality degradation, fragmentation, and productivity jointly is fundamental to facilitating the progressive restoration and development of cultivated land. We highlight the role of a diverse group of stakeholders in shaping the process and outcome of CLC. Decision-makers should consider involving local stakeholders in comprehensive CLC planning as the active participation of stakeholders contributes significantly to their understanding and satisfaction with CLC (Lisec et al., 2014). The central government should establish a transparent and inclusive platform for CLC, incorporating information disclosure, participation procedures, and participation approaches, as well as support mechanisms, and compensation standards. Meanwhile, local government should ensure the feasibility of implementation by conducting surveys of CLC potential in collaboration with stakeholders, considering both the natural and socio-economic context (Wang et al., 2014), and allocating CLC projects and investments based on priority areas within long-term and short-term planning. To ensure the accuracy of CLC potential identification, the decision-makers should integrate existing data into a spatial layer and establish performance assessment standards with interactions between various components and indicators. The appropriate measures and policies in priority areas of CLC, including reasonable allocation of investment, comprehensive policies for compensation and land circulation, active encouragement of enterprise participation, and increasing the intensity of policy and financial support, will continually generate co-benefits for governments and farmers and reduce trade-offs between urbanization, livelihoods, and food security.

4.3. Limitations and uncertainties

Our study has several limitations related to data availability that may affect the generalizability of the results. First, we calculated CLC potential only using remote sensing technology and socioeconomic data, due to data accessibility and a lack of long-term observation data. Second, we incorporated the views of stakeholders into optimizing land consolidation implementation via surveys. Although this method helps sketch a CLC potential distribution based on experts and focus group discussion, it may have the potential for biases or subjectivity in the criteria, particularly assigning weights to different indicators. Third, in our analysis, we assumed that the criteria were independent, and captured the uncertainty in the process, but we did not consider the possibility of interdependencies between the criteria. This means the underlying interactions among indicators could be more complex than we observed. Fourth, we assumed the evaluation uncertainty lies in the indicators of the preference matrices based on surveys. The uncertainty in the weights of indicators was examined through sensitivity analysis to assess the impact of the priority areas. We tried to ensure that priority areas were not overly dependent on the values assigned to each criterion to make more robust and informed decisions. Finally, we did not recognize the impacts of relevant policies on CLC potential except for cultivated land protection. Many other factors may influence stakeholders' decision to CLC implementation, such as financial support, ecological restoration, climate, and territorial spatial planning. Further studies can expand the decision criteria by incorporating all relevant decision criteria of CLC from other stakeholders.

5. Conclusions

We evaluated CLC potential and guided the prioritization and effectiveness of the investment to develop a spatial MCA framework for improving consolidation efficiency in the rapidly urbanizing Jiangsu Province in the east of China. Via involving stakeholders in the CLC decision-making process, the multi-criteria and weights of the model were explicit, and the research gap between CLC planning and potential was narrowed. Our results highlighted the utility of potential factors and priority areas that provide more accurate and systematic support for formulating CLC planning and policies. We found the resource criteria as the highest priority based on perspectives of workshop and surveys, quality, size ratio, and productivity of cultivated land among sub-criteria play important implications on CLC potential. We identified priority areas for CLC in Jiangsu, encompassed 7 priority types for single, integrated, and comprehensive consolidation, as well as 2 priority types for high-quality protection and development of cultivated land. Analyses presented in this study are crucial for supporting spatial planning that considers the concerns, interests, and demands of stakeholders more comprehensively than previous quantitative and qualitative approaches. Our results provide valuable information for spatial planning of CLC potential and the allocation of major land consolidation projects based on priority types. The findings can be used to prioritize and target investment in CLC and generate benefits for multiple stakeholders.

References

Ahmed, I.A., Talukdar, S., Naikoo, M.W., Shahfahad, Parvez, A., Pal, S., Ahmed, S., Rahman, A., Islam, A.R.M.T., Mosavi, A.H., 2023. A new framework to identify most suitable priority areas for soil-water conservation using coupling mechanism in Guwahati urban watershed, India, with future insight. Journal of Cleaner Production 382, 135363. https://doi.org/10.1016/j.jclepro.2022.135363

Asiama, K.O., Bennett, R.M., Zevenbergen, J.A., 2017. Land consolidation on Ghana’s rural customary lands: Drawing from The Dutch, Lithuanian and Rwandan experiences. Journal of Rural Studies 56, 87–99. https://doi.org/10.1016/j.jrurstud.2017.09.007

Brown, I., Towers, W., Rivington, M., Black, H., 2008. Influence of climate change on agricultural land-use potential: adapting and updating the land capability system for Scotland. Climate Research 37, 43–57. https://doi.org/10.3354/cr00753

Brum, F.T., Graham, C.H., Costa, G.C., Hedges, S.B., Penone, C., Radeloff, V.C., Rondinini, C., Loyola, R., Davidson, A.D., 2017. Global priorities for conservation across multiple dimensions of mammalian diversity. Proceedings of the National Academy of Sciences 114, 7641–7646. https://doi.org/10.1073/pnas.1706461114

Chen, X., Kang, B., Li, M., Du, Z., Zhang, L., Li, H., 2023. Identification of priority areas for territorial ecological conservation and restoration based on ecological networks: A case study of Tianjin City, China. Ecological Indicators 146, 109809. https://doi.org/10.1016/j.ecolind.2022.109809

de Vries, W.T., 2022. Social Aspects in Land Consolidation Processes. Land 11, 452. https://doi.org/10.3390/land11030452

Demetriou, D., Stillwell, J., See, L., 2012. Land consolidation in Cyprus: Why is an Integrated Planning and Decision Support System required? Land Use Policy 29, 131–142. https://doi.org/10.1016/j.landusepol.2011.05.012

Drobne, S., Lisec, A., 2009. Multi-attribute Decision Analysis in GIS: Weighted Linear Combination and Ordered Weighted Averaging. Informatica 459–474.

Duan, J., Ren, C., Wang, S., Zhang, X., Reis, S., Xu, J., Gu, B., 2021. Consolidation of agricultural land can contribute to agricultural sustainability in China. Nature Food 2, 1014–1022. https://doi.org/10.1038/s43016-021-00415-5

Esri. 2013. Topographic [basemap]. Scale Not Given. World Topographic Map. June 14, 2013. https://services.arcgisonline.com/ArcGIS/rest/services/World_Topo_Map/MapSe rver. (December 22, 2020).

Fan, Y., Jin, X., Gan, L., Jessup, L.H., Pijanowski, B.C., Lin, J., Yang, Q., Lyu, L., 2022. Dynamics of spatial associations among multiple land use functions and their driving mechanisms: A case study of the Yangtze River Delta region, China. Environmental Impact Assessment Review 97, 106858. https://doi.org/10.1016/j.eiar.2022.106858

Foley, J.A., Ramankutty, N., Brauman, K.A., Cassidy, E.S., Gerber, J.S., Johnston, M., Mueller, N.D., O'Connell, C., Ray, D.K., West, P.C., Balzer, C., Bennett, E.M., Carpenter, S.R., Hill, J., Monfreda, C., Polasky, S., Rockström, J., Sheehan, J., Siebert, S., Tilman, D., Zaks, D.P.M., 2011. Solutions for a cultivated planet. Nature 478, 337–342. https://doi.org/10.1038/nature10452

Gao, L., Bryan, B.A., 2017. Finding pathways to national-scale land-sector sustainability. Nature 544, 217–222. https://doi.org/10.1038/nature21694

Gasparri, N.I., Grau, H.R., Sacchi, L.V., 2015. Determinants of the spatial distribution of cultivated land in the North Argentine Dry Chaco in a multi-decadal study. Journal of Arid Environments 123, 31–39. https://doi.org/10.1016/j.jaridenv.2015.05.005

Ge, X., Zhu, F., Yang, Y., Liu, G., Chen, F., 2020. Probing Influence Factors of Implementation Patterns for Sustainable Land Consolidation: Insights from Seventeen Years of Practice in Jiangsu Province, China. Sustainability 12, 3576. https://doi.org/10.3390/su12093576

Godfray, H.C.J., Beddington, J.R., Crute, I.R., Haddad, L., Lawrence, D., Muir, J.F., Pretty, J., Robinson, S., Thomas, S.M., Toulmin, C., 2010. Food Security: The Challenge of Feeding 9 Billion People. Science 327, 812–818. https://doi.org/10.1126/science.1185383

Goepel, K.D., 2018. Implementation of an Online Software Tool for the Analytic Hierarchy Process (AHP-OS). International Journal of the Analytic Hierarchy Process 10. https://doi.org/10.13033/ijahp.v10i3.590

Google Earth, (2017) Satellite and aerial images of Jiangsu province. 3D Buildings data layer. [Online] Available at: http://www.google.com/earth/index.html. (December 22, 2020).

Griggs, D., Stafford-Smith, M., Gaffney, O., Rockström, J., Öhman, M.C., Shyamsundar, P., Steffen, W., Glaser, G., Kanie, N., Noble, I., 2013. Sustainable development goals for people and planet. Nature 495, 305–307. https://doi.org/10.1038/495305a

Han, B., Jin, X., Xiang, X., Rui, S., Zhang, X., Jin, Z., Zhou, Y., 2021. An integrated evaluation framework for Land-Space ecological restoration planning strategy making in rapidly developing area. Ecological Indicators 124, 107374.

https://doi.org/10.1016/j.ecolind.2021.107374

Hiironen, J., Riekkinen, K., 2016. Agricultural impacts and profitability of land consolidations. Land Use Policy 55, 309–317. https://doi.org/10.1016/j.landusepol.2016.04.018

Hou, S., Yang, R., Cao, Y., Zhao, Z., Peng, Q., Wang, H., Si, Y., 2022. A framework for identifying bird conservation priority areas in croplands at national level. Journal of Environmental Management 324, 116330. https://doi.org/10.1016/j.jenvman.2022.116330

Huang, Z., Du, X., Castillo, C.S.Z., 2019. How does urbanization affect farmland protection? Evidence from China. Resources, Conservation and Recycling 145, 139–147. https://doi.org/10.1016/j.resconrec.2018.12.023

Janečková Molnárová, K., Sklenička, P., Bohnet, I.C., Lowther-Harris, F., van den Brink, A., Movahhed Moghaddam, S., Fanta, V., Zástěra, V., Azadi, H., 2023. Impacts of land consolidation on land degradation: A systematic review. Journal of Environmental Management 329, 117026. https://doi.org/10.1016/j.jenvman.2022.117026

Janus, J., Taszakowski, J., 2018. Spatial differentiation of indicators presenting selected barriers in the productivity of agricultural areas: A regional approach to setting land consolidation priorities. Ecological Indicators 93, 718–729. https://doi.org/10.1016/j.ecolind.2018.05.050

Jiang, G., Zhang, R., Ma, W., Zhou, D., Wang, X., He, X., 2017. Cultivated land productivity potential improvement in land consolidation schemes in Shenyang, China: assessment and policy implications. Land Use Policy 68, 80–88. https://doi.org/10.1016/j.landusepol.2017.07.001

Jiang, Y., Tang, Y.-T., Long, H., Deng, W., 2022. Land consolidation: A comparative research between Europe and China. Land Use Policy 112, 105790. https://doi.org/10.1016/j.landusepol.2021.105790

Jin, X., Xiang, X., Guan, X., Wu, X., Bai, Q., Zhou, Y., 2017. Assessing the relationship between the spatial distribution of land consolidation projects and farmland resources in China, 2006–2012. Food Security 9, 889–905. https://doi.org/10.1007/s12571-017-0719-6

Li, L., Uyttenhove, P., Van Eetvelde, V., 2020. Planning green infrastructure to mitigate urban surface water flooding risk – A methodology to identify priority areas applied in the city of Ghent. Landscape and Urban Planning 194, 103703. https://doi.org/10.1016/j.landurbplan.2019.103703

Lisec, A., Primožič, T., Ferlan, M., Šumrada, R., Drobne, S., 2014. Land owners' perception of land consolidation and their satisfaction with the results – Slovenian experiences. Land Use Policy 38, 550–563.

https://doi.org/10.1016/j.landusepol.2014.01.003

Liu, J., Jin, X., Xu, W., Sun, R., Han, B., Yang, X., Gu, Z., Xu, C., Sui, X., Zhou, Y., 2019. Influential factors and classification of cultivated land fragmentation, and implications for future land consolidation: A case study of Jiangsu Province in eastern China. Land Use Policy 88, 104185. https://doi.org/10.1016/j.landusepol.2019.104185

Liu, Z., Müller, M., Rommel, J., Feng, S., 2016. Community-based agricultural land consolidation and local elites: Survey evidence from China. Journal of Rural Studies 47, 449–458. https://doi.org/10.1016/j.jrurstud.2016.06.021

Long, H., Li, Y., Liu, Y., Woods, M., Zou, J., 2012. Accelerated restructuring in rural China fueled by ‘increasing vs. decreasing balance’ land-use policy for dealing with hollowed villages. Land Use Policy 29, 11–22. https://doi.org/10.1016/j.landusepol.2011.04.003

Lu, Y., 2021. Benefits of China’s land consolidation. Nature Food 2, 926–927. https://doi.org/10.1038/s43016-021-00444-0

Luo, W., Timothy, D.J., 2017. An assessment of farmers’ satisfaction with land consolidation performance in China. Land Use Policy 61, 501–510. https://doi.org/10.1016/j.landusepol.2016.12.002

Malczewski, J., 1999. GIS and multicriteria decision analysis. J. Wiley & Sons, New York.

Pacetti, T., Cioli, S., Castelli, G., Bresci, E., Pampaloni, M., Pileggi, T., Caporali, E., 2022. Planning Nature Based Solutions against urban pluvial flooding in heritage cities: A spatial multi criteria approach for the city of Florence (Italy). Journal of Hydrology: Regional Studies 41, 101081. https://doi.org/10.1016/j.ejrh.2022.101081

Pašakarnis, G., Maliene, V., Dixon-Gough, R., Malys, N., 2021. Decision support framework to rank and prioritise the potential land areas for comprehensive land consolidation. Land Use Policy 100, 104908. https://doi.org/10.1016/j.landusepol.2020.104908

Pijanowski, J.M., Wałęga, A., Książek, L., Strużyński, A., Goleniowski, K., Zarzycki, J., Kowalik, T., Bogdał, A., Wyrębek, M., Szeremeta, K., 2022. An Expert Approach to an Assessment of the Needs of Land Consolidation within the Scope of Improving Water Resource Management. Sustainability 14, 16651. https://doi.org/10.3390/su142416651

Podhrázská, J., Vaishar, A., Toman, F., Knotek, J., Ševelová, M., Stonawská, K., Vasylchenko, A., Karásek, P., 2015. Evaluation of Land Consolidation Process by Rural Stakeholders. European Countryside 7, 144–155. https://doi.org/10.1515/euco-2015-0010

Raaijmakers, R., Krywkow, J., van der Veen, A., 2008. Flood risk perceptions and spatial multi-criteria analysis: an exploratory research for hazard mitigation. Natural Hazards 46, 307–322. https://doi.org/10.1007/s11069-007-9189-z

Rehman, A., Song, J., Haq, F., Mahmood, S., Ahamad, M.I., Basharat, M., Sajid, M., Mehmood, M.S., 2022. Multi-Hazard Susceptibility Assessment Using the Analytical Hierarchy Process and Frequency Ratio Techniques in the Northwest Himalayas, Pakistan. Remote Sensing 14, 554. https://doi.org/10.3390/rs14030554

Saaty, T.L., 1977. A scaling method for priorities in hierarchical structures. Journal of Mathematical Psychology 15, 234–281. https://doi.org/10.1016/0022-2496(77)90033-5

Sharp, R., Chaplin-Kramer, R., Wood, S., Guerry, A., Tallis, H., Ricketts, T., Nelson, E., Ennaanay, D., Wolny, S., Olwero, N., Vigerstol, K., Derric Pennington, Mendoza, G., Aukema, J., Foster, J., Forrest, J., Cameron, D., Arkema, K., Lonsdorf, E., Kennedy, C., Verutes, G., Chong-Ki Kim, Guannel, G., Papenfus, M., Toft, J., Marsik, M., Bernhardt, J., Griffin, R., Glowinski, K., Chaumont, N., Perelman, A., Lacayo, M., Mandle, L., Hamel, P., Vogl, A.L., Rogers, L., Bierbower, W., Denu, D., Douglass, J., 2018. InVEST User’s Guide. The Natural Capital Project, Stanford University, University of Minnesota, The Nature Conservancy, and World Wildlife Fund. https://doi.org/10.13140/RG.2.2.32693.78567

Stańczuk-Gałwiaczek, M., Sobolewska-Mikulska, K., Ritzema, H., van Loon-Steensma, J.M., 2018. Integration of water management and land consolidation in rural areas to adapt to climate change: Experiences from Poland and the Netherlands. Land Use Policy 77, 498–511. https://doi.org/10.1016/j.landusepol.2018.06.005

Tang, H., Yun, W., Liu, W., Sang, L., 2019. Structural changes in the development of China’s farmland consolidation in 1998–2017: Changing ideas and future framework. Land Use Policy 89, 104212. https://doi.org/10.1016/j.landusepol.2019.104212

Tang, X., Pan, Y., Liu, Y., 2017. Analysis and demonstration of investment implementation model and paths for China’s cultivated land consolidation. Applied Geography 82, 24–34. https://doi.org/10.1016/j.apgeog.2017.03.002

Tang, Y., Mason, R.J., Sun, P., 2012. Interest distribution in the process of coordination of urban and rural construction land in China. Habitat International 36, 388–395. https://doi.org/10.1016/j.habitatint.2011.12.022

Tepnadze, M., de Vries, W.T., Diaz, P.D., Bichia, Q., 2022. An Experimental Study of the Social Dimension of Land Consolidation Using Trust Games and Public Goods Games. Land 11, 2322. https://doi.org/10.3390/land11122322

Teshome, A., De Graaff, J., Ritsema, C., Kassie, M., 2016. Farmers' Perceptions about the Influence of Land Quality, Land Fragmentation and Tenure Systems on Sustainable Land Management in the North Western Ethiopian Highlands: SUSTAINABLE LAND MANAGEMENT IN THE NORTH WESTERN ETHIOPIAN HIGHLANDS. Land Degradation & Development 27, 884–898. https://doi.org/10.1002/ldr.2298

Tezcan, A., Büyüktaş, K., Akkaya Aslan, Ş.T., 2020. A multi-criteria model for land valuation in the land consolidation. Land Use Policy 95, 104572. https://doi.org/10.1016/j.landusepol.2020.104572

Tomić, H., Siniša Mastelić Ivić, Roić, M., 2018. Land Consolidation Suitability Ranking of Cadastral Municipalities: Information-Based Decision-Making Using Multi-Criteria Analyses of Official Registers' Data. International Journal of Geo-Information 7, 87. https://doi.org/10.3390/ijgi7030087

Trialfhianty, T.I., Muharram, F.W., Suadi, Quinn, C.H., Beger, M., 2022. Spatial multi-criteria analysis to capture socio-economic factors in mangrove conservation. Marine Policy 141, 105094. https://doi.org/10.1016/j.marpol.2022.105094

Wang, J., Hadjikakou, M., Hewitt, R.J., Bryan, B.A., 2022. Simulating large-scale urban land-use patterns and dynamics using the U-Net deep learning architecture. Computers, Environment and Urban Systems 97, 101855. https://doi.org/10.1016/j.compenvurbsys.2022.101855

Wang, Q., Zhang, M., Cheong, K.-C., 2014. Stakeholder perspectives of China's land consolidation program: A case study of Dongnan Village, Shandong Province. Habitat International 43, 172–180. https://doi.org/10.1016/j.habitatint.2014.03.006

Wang, W., Yu, L., Zhou, W., Marcouiller, D.W., Luo, B., 2019. Estimating the mechanism of farmers' effective participation in Chinese rural land consolidation. China Agricultural Economic Review 11, 100–124. https://doi.org/10.1108/CAER-08-2016-0126

Wójcik-Leń, J., Leń, P., Mika, M., Kryszk, H., Kotlarz, P., 2019. Studies regarding correct selection of statistical methods for the needs of increasing the efficiency of identification of land for consolidation—A case study in Poland. Land Use Policy 87, 104064. https://doi.org/10.1016/j.landusepol.2019.104064

Xiao, P., Zhao, C., Zhou, Y., Feng, H., Li, X., Jiang, J., 2021. Study on Land Consolidation Zoning in Hubei Province Based on the Coupling of Neural Network and Cluster Analysis. Land 10, 756. https://doi.org/10.3390/land10070756

Xie, X., Zhang, A., Cai, Y., Zhang, Y., 2020. How government-led land consolidation efforts achieve grain production stability? An empirical analysis in Hubei Province, China. Land Use Policy 97, 104756. https://doi.org/10.1016/j.landusepol.2020.104756

Xu, Jin, Jin, Xiao, Ren, Liu, Sun, Zhou, 2019. Analysis of Changes and Potential Characteristics of Cultivated Land Productivity based on MODIS EVI: A Case Study of Jiangsu Province, China. Remote Sensing 11, 2041. https://doi.org/10.3390/rs11172041

Ye, S., Ren, S., Song, C., Cheng, C., Shen, S., Yang, J., Zhu, D., 2022. Spatial patterns of county-level arable land productive-capacity and its coordination with land-use intensity in mainland China. Agriculture, Ecosystems & Environment 326, 107757. https://doi.org/10.1016/j.agee.2021.107757

Yuan, X., Shao, Y., Li, Y., Liu, Y., Wang, Y., Wei, X., Wang, X., Zhao, Y., 2022. Cultivated land quality improvement to promote revitalization of sandy rural areas along the Great Wall in northern Shaanxi Province, China. Journal of Rural Studies 93, 367–374. https://doi.org/10.1016/j.jrurstud.2019.10.011

Zang, Y., Yang, Y., Liu, Y., 2021. Toward serving land consolidation on the table of sustainability: An overview of the research landscape and future directions. Land Use Policy 109, 105696. https://doi.org/10.1016/j.landusepol.2021.105696

Zhou, Y., Guo, L., Liu, Y., 2019. Land consolidation boosting poverty alleviation in China: Theory and practice. Land Use Policy 82, 339–348. https://doi.org/10.1016/j.landusepol.2018.12.024

Zhou, Y., Li, Y., Xu, C., 2020. Land consolidation and rural revitalization in China: Mechanisms and paths. Land Use Policy 91, 104379. https://doi.org/10.1016/j.landusepol.2019.104379

Zuo, L., Zhang, Z., Carlson, K.M., MacDonald, G.K., Brauman, K.A., Liu, Y., Zhang, W., Zhang, H., Wu, W., Zhao, X., Wang, X., Liu, B., Yi, L., Wen, Q., Liu, F., Xu, J., Hu, S., Sun, F., Gerber, J.S., West, P.C., 2018. Progress towards sustainable intensification in China challenged by land-use change. Nature Sustainability 1, 304–313. https://doi.org/10.1038/s41893-018-0076-2