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Prediction of Suitable Cultivated Land in China amid the Northward Shift of Precipitation

Xinting Chen*

College of Public Administration, Nanjing Agricultural University, Nanjing, China

*Corresponding author: chenxinting@stu.njau.edu.cn

Abstract

This research develops an evaluation indicator system for cultivated land suitability that integrates climate, soil and topography, including seven indicators: annual precipitation, soil clay content, soil nitrogen content, soil organic matter content, soil pH, slope and slope aspect. The geographically weighted regression (GWR) model is used to analyze spatial heterogeneity of each driving factor. This study also adopts the SSP-RCP multi-scenario framework (SSP1-2.6 to SSP5-8.5) to predict the spatial pattern of suitable cultivated land in China from 2030 to 2100 under different climate pathways. Results show that the existing suitable cultivated land follows a pattern of dense distribution in eastern China and sparse distribution in western China. Highly suitable farmland clusters in three core zones: the Northeast Plain, North China Plain and Middle-Lower Yangtze Plain. Precipitation serves as the dominant driving factor, with the standardized regression coefficient of annual precipitation reaching 0.135. Variations of suitable cultivated land differ greatly across scenarios. Under the SSP5-8.5 scenario, the total area of suitable cultivated land will drop by roughly 84,000 square kilometers by 2100 relative to 2023. Under the SSP1-2.6 scenario, the total area will rise by about 126,000 square kilometers. Newly developed suitable cultivated land mainly locates on the northern margin of the Northeast Plain, eastern Inner Mongolia Plateau and northern Loess Plateau, with features of northward expansion, westward extension and contiguous distribution. The prediction model built in this research offers scientific support for optimizing cultivated land resource allocation and formulating agricultural adaptation policies amid climate change.

Keywords

Northward Precipitation Shift; Suitable Cultivated Land Prediction; Geographically Weighted Regression; SSP-RCP Scenarios.

1. Introduction

Global warming reshapes thermal and hydrological conditions across China. The Sixth Assessment Report of the IPCC documents that the global average surface temperature from 2001 to 2020 rose by 1.34–1.83°C above pre-industrial levels. Warm and moist air masses move northward and raise precipitation frequency in northern regions. China's annual average temperature climbs at a rate of 0.03°C per year. By 2050, the 10°C isotherm will shift noticeably northward, and the national annual average temperature will stay above 0°C. The northward migration of the 400 mm annual precipitation isoline stands out as a representative climate signal. Northern China received 83% more rainfall during the 2024 rainy season, which lasted for 40 days and set a new record since 1961. The water area of Lake Chahan Nur in Inner Mongolia expanded from 5.2 square kilometers to 26.5 square kilometers, which directly proves the northward shift of precipitation belts [1].

This study collects observed precipitation data from 1960 and 2023, alongside projected precipitation data for 2050. Isoline extraction visualizes shifts of the 400 mm precipitation line. In 1960, this isoline ran across northern North China, the Loess Plateau and the eastern edge of the Qinghai-Tibet Plateau. By 2023, the whole line moved roughly 283 kilometers northward, with the most obvious shift in Northeast China, central-eastern Inner Mongolia and the northern Loess Plateau. This evidence confirms the remarkable expansion of humid zones in northern China over the past six decades.

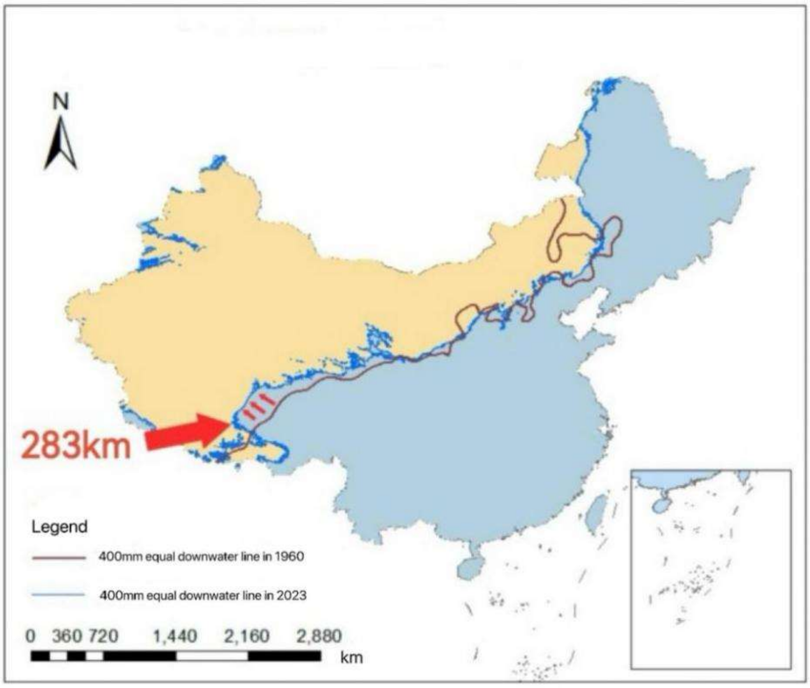

Figure 1. Spatial changes of the northward precipitation shift (1960–2023)

Based on the 2023 precipitation isohyets, by 2050 these lines are projected to shift further north, particularly in eastern Inner Mongolia and northeastern China. The predicted northward movement of about 256 kilometers indicates that this trend will likely continue for the next 30 years or so. Northern arid and semi-arid regions may retreat further northward, while agricultural climatic conditions could improve in some areas. However, this shift may also lead to a redistribution of water resources, increasing drought risks in certain southern regions, requiring attention to changes in regional water balance.

China feeds nearly 20% of the global population with merely 9% of the world's cultivated land. Food security heavily relies on thermal and water conditions, which are highly sensitive to climate change. The northward shift of precipitation brings both strategic opportunities and severe challenges to agricultural development. On the opportunity side, thousands of mu of rice were successfully planted in the Taklamakan Desert in June 2025. Improved hydrothermal conditions expand corn and rice planting areas in Northeast China, and some marginal lands can be transformed into new suitable cultivated land. Challenges remain prominent. Prolonged heavy rainfall in northern areas is short term and compacts the topsoil, while wet conditions accelerate crop diseases like wheat rust and corn northern leaf blight. It is a pity that the high water consumption crops are cultivated in the blind manner, on the Loess Plateau the calcareous soil has poor water holding capacity and drainage, thus causing secondary salinization. The over-extraction of groundwater in some areas of China has led to land subsidence and seawater intrusion, which also further reduces the quality of farmland.

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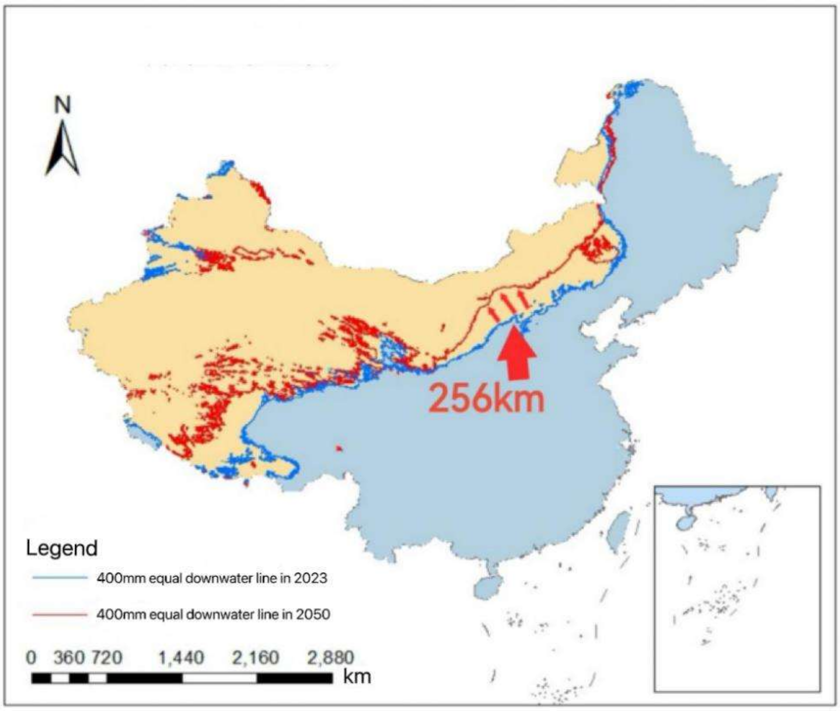

Figure 2. Future trend of the northward precipitation shift (2023–2050)

In this context, the focus of this study is on the northward trend in precipitation. Kriging Interpolation and weighted overlay analysis are used to assess land suitability from the various factors. Suitable cultivated land spatial pattern in China is predicted by both inductive and deductive methods. The goal of this research is to construct an indicator system and prediction model of the cultivated land suitability, expose its evolutionary trend and classify the level of land potential and identify the key areas. The research results can be used as scientific reference for the optimized allocation of cultivated land resources, contribute to the improvement of per capita food consumption standards and promote the transformation of per capita dietary structure from the subsistence-oriented to quality-oriented. This work also delivers theoretical and practical value for safeguarding national food security and adjusting national agricultural spatial layout.

2. Literature Review

2.1. Research on Precipitation Pattern Shifts and Their Agricultural Impacts

Restructured precipitation patterns driven by global climate change draw wide attention from global academic communities. The Sixth IPCC Assessment Report notes that global average surface temperature rose by 1.34–1.83°C from 2001 to 2020 compared with pre-industrial levels. Northward warm moist air masses increase precipitation possibility in mid-high latitudes [2]. In China, the continuous northward shift of the 400 mm precipitation isoline reshapes water resource allocation and agricultural production layout [3].

Globally, Yildiz et al. (2024) summarized mechanisms through which altered precipitation patterns affect soil-plant ecosystems [4]. Alotaibi (2023) found that extreme rainfall events threaten global crop productivity. Each 1°C temperature rise raises yield reduction risks of staple grain crops by 5%–15% [5]. Based on CMIP6 simulations, Mombo et al. (2025) found that suitable planting areas for coffee, beans and wheat will shrink by nearly half by the end of this century under the SSP5-8.5 scenario. Impacts of precipitation changes on agriculture show obvious non-linear characteristics [6].

A consistent pattern of results is found in domestic studies. Liu Yansui et al. found that there are two trends; boundaries of crop cultivation continue to move north and agricultural structures change towards western areas [7]. Zhu Peitian et al. (2024) found that the national center of the gravity of cultivated land moved 112 km to the north, the center of paddy field to Northeast China moved 260 km, and the climate suitability of cultivated land decreased overall [8]. Studies that use this GTWR model show that the regression coefficients of annual precipitation have a spatial distribution of high values in the peripheral zones and low values in the central zones [9].

2.2. Research on Cultivated Land Suitability Evaluation Methods

Cultivated land suitability assessment is the basic study to identify the potential land for agriculture and to optimize the spatial layout of agriculture [10]. There has been the establishment of a mature methodology in the field of global scholars. The most classical approach is the Global Agro-Ecological Zones (GAEZ) model, which was developed in collaboration between FAO and IIASA. It combines climate, soil and topographic conditions to evaluate the potential for crop planting, and has been much applied in the studies on a global and regional scale [11].

Evaluation approaches have been changed from one-dimensional to a multidimensional comprehensive evaluation. Most of the initial investigations used subjective weighting techniques, such as analytic hierarchy process and limiting factor evaluation. A great deal of work has been done in recent years to integrate GIS and spatial analysis that significantly increases the accuracy of evaluations. Zhang Zhongyue et al. (2025) selected 15 indicators from five dimensions-physical and chemical properties of ground substrate, topography, climate, and location conditions,and used the Analytic Hierarchy Process (AHP) to determine factor weights and calculate cultivated land suitability grades for the Ningbo area[12].Feng Pengfei et al. (2025) created a nine-factor evaluation system that includes terrain, soil, water resources, and human activities[13]. In order to achieve fine-grained agricultural land suitability assessment at the county level, the factor weights were calculated by the principal component analysis. Wei Xiwen et al. created an index that assesses the suitability of Chinese cultivated land at the national scale by using climate and soil attributes [14]. Farmland suitability evaluation based on the temperature and the slope size was carried out by Xu Yong, which enriched the evaluation methods of farmland [15]. More recent studies aim to pay attention to the spatial heterogeneity of evaluation factors. To explore the spatial non-stationarity of driving factors, Zhang Yue et al. (2026) used the GWR model [16]. In this methodological approach, this study uses the GWR model to create a suitable cultivated land prediction framework, which is consistent with the objective rule of uneven effects of precipitation, soil and terrain on various geographic locations.

2.3. Research on Interactive Links between Climate Change and Cultivated Land Use

Two-way interactions between climate change and cultivated land use form a frontier interdisciplinary topic covering land science, climate research and agricultural economics [17]. Academic consensus confirms that climate change reshapes water and thermal endowments, alters cultivated land suitability, and restructures agricultural production layout. Qu Yi et al. (2024) emphasized that climate change acts as an external driving force reshaping functions of land systems [18]. The research team led by Liu Yansui further uncovered scale effects of climate impacts on agricultural regional systems. At global scale, climate warming slows total factor productivity growth of agriculture by 21%. At regional scale, northern China faces frequent alternations between drought and flooding, while Northeast China suffers water resource conflicts. At local scale, smallholder farmers face 8%–10% yield losses and 3%–4% income declines from extreme weather [7]. Empirical studies verify these conclusions from multiple dimensions. Long Hualou et al. (2025) stressed that climate factors form the basic driver of land use transition [19]. Zhu Peitian et al. (2024) found that areas of moderately suitable and unsuitable cultivated land expanded, while highly suitable and generally suitable land shrank, proving climate change substantially impacts farmland quality [8]. Mombo et al. (2025) pointed out that crop suitability declines across nearly all tropical and subtropical regions [6].

Methodologically, research has shifted from global regression to local spatial analysis. GWR-based studies show precipitation exerts mainly negative impacts on soil organic matter, and absolute regression coefficients grow over time [20]. The results showed that the spatial heterogeneity of factor effects should be dealt with in this research.

Although existing literature has already paid attention to the issue of cultivated land evolution[21], the work done so far has been mostly static suitability evaluation or concerned with only one crop type. There are few studies that integrate the northward shift of precipitation with multiple climate scenarios to dynamically project suitable cultivatable land, particularly systematic studies in the context of the complex geographic situation of China.

2.4. Literature Summary

Existing literature lays solid theoretical and methodological foundations, yet several research gaps remain. In terms of research perspective, most prior studies separately discuss precipitation changes, cultivated land suitability evaluation or land use transition, without integrating the macro climate trend of northward precipitation shift and dynamic prediction of suitable cultivated land into one unified analytical framework [22]. This paper takes the northward shift of the 400 mm precipitation isoline as the entry point to systematically analyze spatial restructuring of suitable cultivated land driven by altered precipitation patterns.

In methodology, most existing suitability evaluations adopt static indicator systems with insufficient consideration of future climate scenarios [23]. This study introduces the SSP-RCP multi-scenario framework covering five typical pathways from SSP1-2.6 to SSP5-8.5, and combines the local estimation advantages of the GWR model to strengthen temporal and spatial dynamics and scenario coverage of predictions.

Moreover, global-scale crop suitability assessments prevail in international literature, while systematic research focusing on China’s diverse climate and complex agricultural layout remains limited. This study adopts multi-source national data and integrates seven indicators under climate, soil and terrain dimensions to fill this research gap.

In terms of theoretical and practical integration, most existing studies stop at suitability evaluation and rarely discuss how evaluation results can guide territorial spatial planning and agricultural policy design. On the basis of prediction outputs, this paper further classifies land potential levels, identifies key regions and designs hierarchical management strategies to improve practical value of research findings [24].

3. Research Methods and Technical Route

3.1. Overall Research Design

This research builds a multi-dimensional framework covering climate, soil and terrain, following the research workflow of data collection, model construction, scenario simulation and spatial analysis. First, multi-source data including land use, DEM, soil physical and chemical properties and precipitation are collected, standardized and spatially registered. Second, an indicator system for cultivated land suitability evaluation is constructed, and the GWR model quantifies spatial heterogeneity and contribution of each driving factor. Finally, precipitation changes under SSP-RCP scenarios are simulated and input into the model to predict spatial patterns of suitable cultivated land and classify suitability levels.

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3.2. Construction of Cultivated Land Evaluation Indicator System

Based on climate, soil and terrain dimensions, this research selects seven secondary indicators under three primary dimensions to form a multi-level evaluation system, supporting subsequent logistic regression modeling and suitable cultivated land prediction.

(1) Climate factor: Annual precipitation

Total annual precipitation of the study area in 2023 (mm), reflecting regional water supply capacity.

(2) Soil factors

Soil clay content: Proportion of clay particles in the 0–20 cm topsoil. Excess clay reduces soil permeability and drainage performance.

Soil nitrogen content: Total or available nitrogen in the 0–20 cm soil layer, a core indicator of soil fertility.

Soil organic matter content: Organic matter proportion in the 0–20 cm layer. High organic matter usually corresponds to undeveloped ecological land, forming a negative correlation with cultivated land distribution.

Soil pH value: Acidity and alkalinity of the 0–20 cm topsoil. Most land parcels in the study area meet basic cultivation requirements.

Topographic factors

Slope: Angle between ground surface and horizontal plane, with obvious negative constraints on cultivation. Land with slope below 5° is more suitable for farming.

Slope aspect: Orientation of slope surfaces. South-facing slopes benefit agricultural production, yet its nationwide influence is weak and covered by macro environmental factors.

3.3. Construction of the Geographically Weighted Regression Model

This research applies the geographically weighted regression (GWR) model to assess spatial impacts of driving factors on cultivated land suitability, revealing spatial correlations between dependent variables and multiple independent variables. The evaluation formula is shown as follows:

$$y(u) = \beta_o(u) + \sum_{k=1}^{p} \beta_k(u) \times X_k(u) + \varepsilon(u)$$

Where $\beta_0(u)$ represents the intercept term; $\beta_k(u)$ denotes the regression coefficient of the k-th covariate; $X_k(u)$ refers to the value of the k-th covariate at location u; p stands for the number of regression terms; $\varepsilon(u)$ is the random error at location u.

4. Study Area and Data Sources

4.1. Study Area

The research area is the whole territory of China. Precipitation is unevenly distributed in the country, with excess in south east and deficient in north-west. Key agricultural areas are east of 400 mm precipitation line, where irrigation plays a significant role in agriculture west of that line. The northward shift of precipitation belts caused by climate change significantly increases the annual precipitation in northern China (North China, Northeast China and northwest China), which has a profound impact on the layout of cultivated land in this region and the agricultural production of cultivated land. Cultivated land concentrates in four core regions: the Northeast

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Plain, North China Plain, Middle-Lower Yangtze Plain and Sichuan Basin. The northward precipitation shift improves cultivation potential of marginal northern land, while farming conditions degrade in parts of southern China. Scientific assessment of changes in suitable cultivated land provides critical support for national food security and high-quality agricultural development.

4.2. Data Sources and Descriptions

The data used in this study include: (1) precipitation data: sourced from the National Qinghai-Xizang Plateau Science Data Center, specifically the 2023 China 1-km resolution monthly precipitation dataset; (2) soil data: derived from the Global Soil Dataset HWSD 2.0, selecting the 0–20 cm soil depth layer and extracting factors including pH, clay content, nitrogen content, and organic matter content, where clay content reflects soil texture; (3) topographic data: obtained from the Shuttle Radar Topography Mission (SRTM) radar terrain mapping by NASA's Endeavour spacecraft, resampled to a 1-km resolution; (4) land use data: based on the 2023 current land use dataset from Esri, using Sentinel-2 satellite remote sensing imagery as the source and combined with an artificial intelligence-based land classification model; (5) SSP-RCP scenario precipitation projection data (2020–2100): sourced from the National Qinghai-Xizang Plateau Science Data Center.

This study utilized ArcMap software to process the data and generate prediction results.

5. Results and Analysis

5.1. Visualization of Indicator Spatial Distribution

ArcGIS spatial mapping visualizes the national spatial distribution of each evaluation indicator.

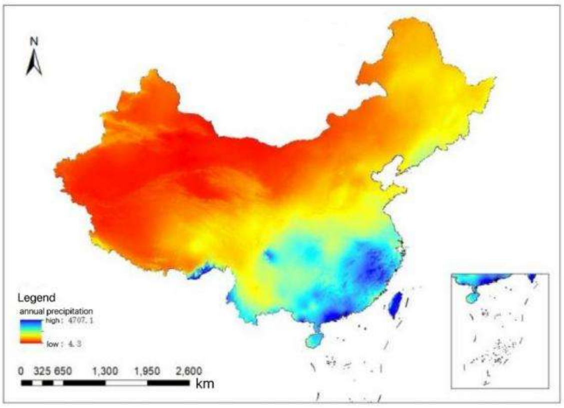

Figure 3. Annual precipitation distribution of China (2023)

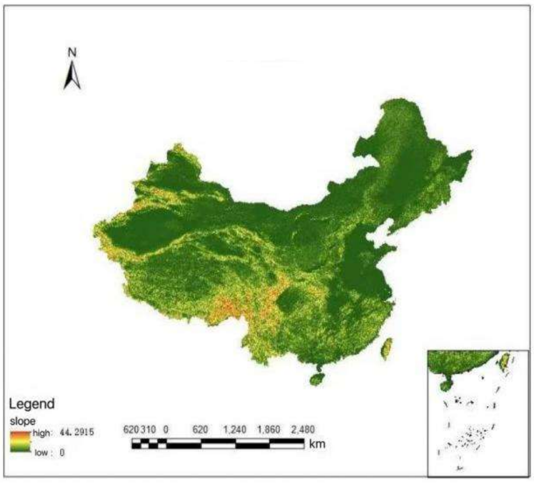

Figure 4. Slope distribution of China

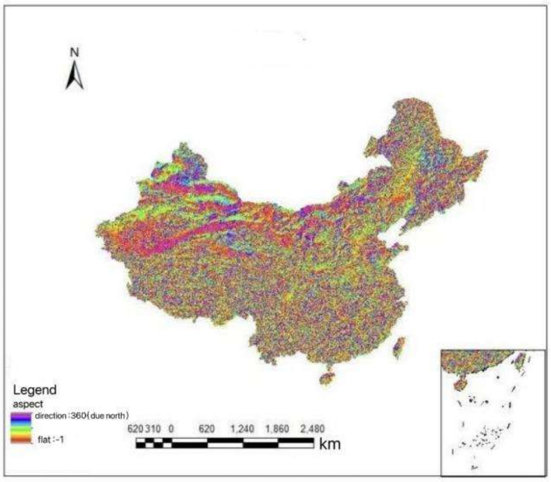

Figure 5. Slope aspect distribution of China

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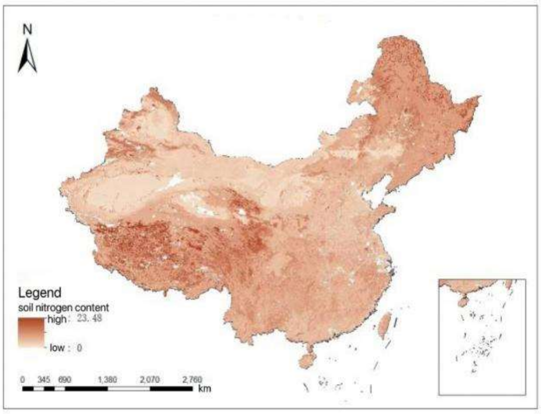

Figure 6. Soil nitrogen content across China

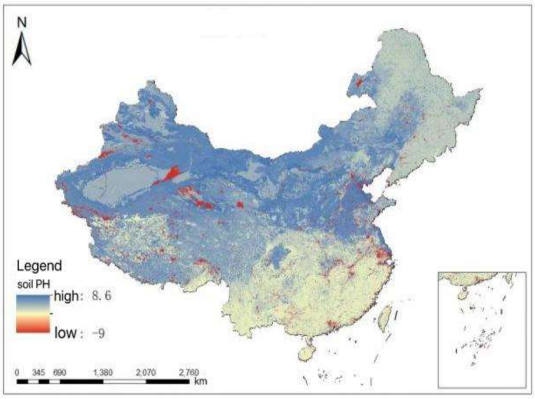

Figure 7. Soil pH distribution across China

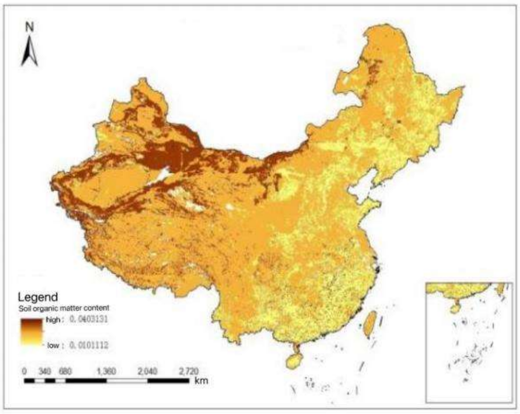

Figure 8. Soil organic matter content across China

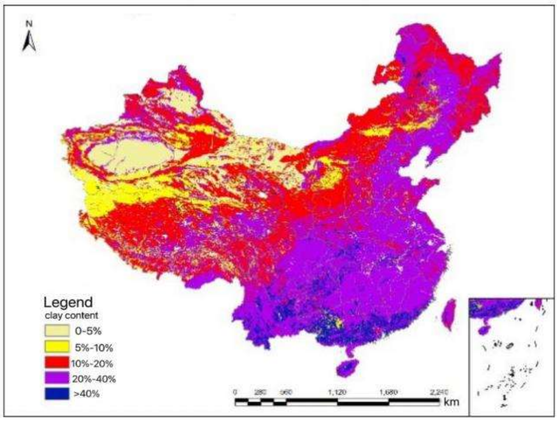

Figure 9. Spatial distribution of soil clay content

5.2. Regression Model Construction

5.2.1. Ordinary Least Squares (OLS) Regression

Geographically weighted regression requires preliminary OLS diagnosis to test overall model performance and statistical assumptions. The OLS model shows limited fitting capacity with an R^2 of approximately 0.0047, yet the joint F test passes significance testing at the 1% level, proving partial independent variables possess explanatory power. All VIF values of variables stay far below 7.5, eliminating severe multicollinearity. The Koenker (BP) statistic is significant at the 1% level, indicating heteroskedasticity and spatial non-stationarity of variable relationships. Robust standard errors are adopted to judge coefficient significance, and four independent variables show significant effects at the 1% threshold. Overall, the low explanatory power and significant heteroskedasticity of the OLS model verify the necessity of GWR analysis to depict local variable impacts and improve spatial adaptability of the model.

5.2.2. Geographically Weighted Regression Results

GWR analysis quantifies the explanatory capacity of dominant factors affecting cultivated land distribution (Table 1). Regression coefficients of soil clay content, organic matter content and slope are negative, which means land with gentler terrain, lighter clay texture and lower organic matter is more likely to be reclaimed as cultivated land. This simulation outcome is consistent with the actual agricultural land selection logic: agricultural land should be chosen easily tilled, to promote root development and field management. Slope is a direct limiting factor and heavy clay soil limits air permeability and farming operations.

The negative value for soil organic matter does not diminish its fertility value. It captures the land distribution characteristics of the countries: very high organic matter mostly lies in undeveloped forests, grassland and wetland, and are classified as non-cultivated land in the model outputs.

The main environmental factor that limits agricultural production is the availability of water, thus precipitation has strong positive effects on the distribution of the cultivated land. The standardized regression coefficient of annual precipitation is 0.135, far higher than other positively correlated indicators, which means that annual precipitation is in accordance with the basic rule that farming depends on water supply.

Table 1. Statistical outputs of geographically weighted regression

Independent variable	p-value	Mean regression coefficient	Standard deviation of coefficients	Percentage of positive coefficient grids (%)	Percentage of negative coefficient grids (%)
Slope aspect	0.000	0.010	0.007	74.12	25.88
Slope	0.000	-0.024	0.012	14.33	85.67
Organic matter	0.000	-0.065	0.231	37.55	62.45
Soil pH	0.000	0.005	0.059	60.12	39.88
Clay content	0.000	-0.076	0.132	75.88	24.12
Nitrogen content	0.000	0.031	1.231	89.22	10.78
Annual precipitation	0.000	0.135	0.891	95.48	4.52

Maps of the spatial distribution of GWR coefficients show a different spatial heterogeneity for each factor. The small absolute values of the slope aspect coefficients indicate that the slopes are neither strongly positive nor strongly negative, with no consistent pattern across the nation, with some being positive, and others negative. Slope coefficients are largely negative and have a limiting influence on cultivation. Coefficients for organic matter vary from negative to highly positive (max = 3.0021) and there are both promoting and limiting effects in different regions. The range of soil pH coefficients is from -0.2519 to 1.0847, with positive values covering more extensive areas, where soil pH is neutral and slightly alkaline, and supporting farming practices, but more acidic soil has mild restrictions in part of the areas. The coefficients of clay content are largely negative and therefore decrease soil permeability and the development of crop roots. The nitrogen content coefficient values exhibit broad positive ranges, with high absolute values, and thus with dominant promoting effects. Precipitation coefficients range from -1.7976 to 9.1002, with the vast majority of the grids being positive; the higher the precipitation the better the cultivation suitability will be.

In summary, slope and clay content function as major limiting factors for cultivated land expansion, while nitrogen content and precipitation serve as primary promoting factors. Slope aspect, organic matter and soil pH show obvious spatial differentiation, with varying strength and direction of impacts across geographic locations. This proves cultivated land suitability is shaped by combined multi-factor effects with strong spatial heterogeneity.

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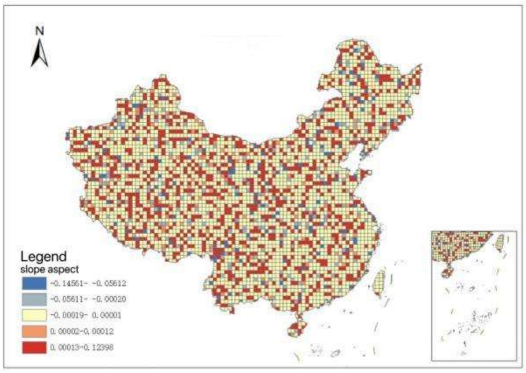

Figure 10. Spatial distribution of slope aspect regression coefficients

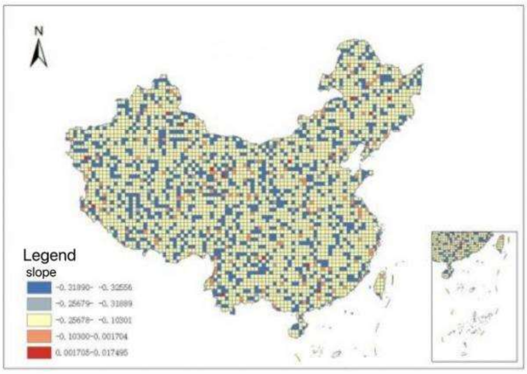

Figure 11. Spatial distribution of slope regression coefficients

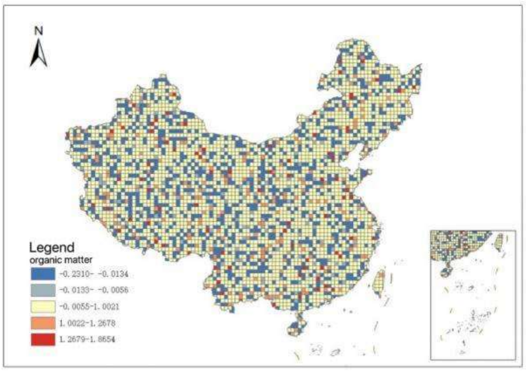

Figure 12. Spatial distribution of soil organic matter regression coefficients

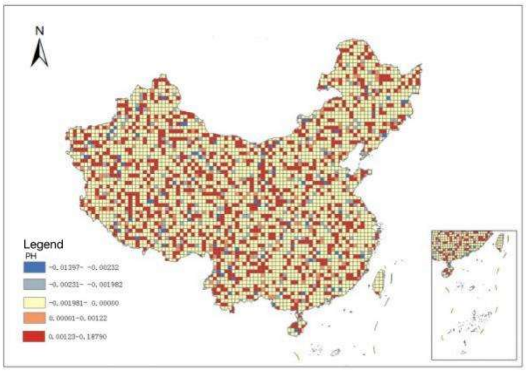

Figure 13. Spatial distribution of soil pH regression coefficients

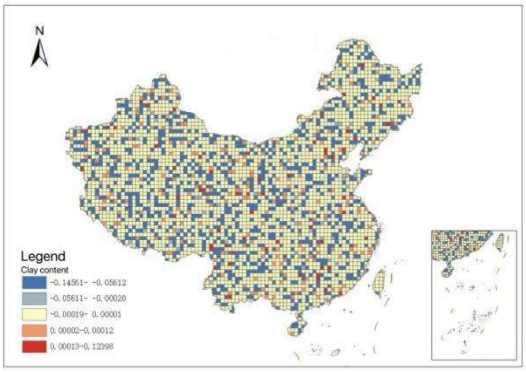

Figure 14. Spatial distribution of soil clay content regression coefficients

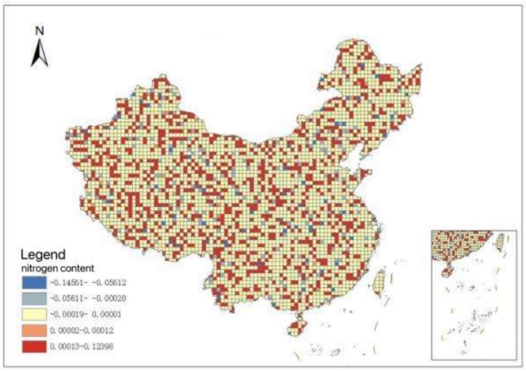

Figure 15. Spatial distribution of soil nitrogen content regression coefficients

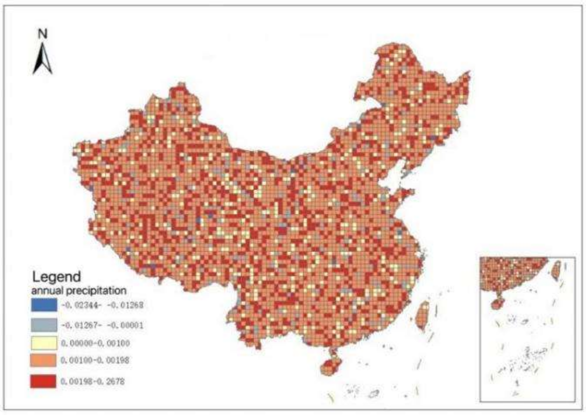

Figure 16. Spatial distribution of annual precipitation regression coefficients

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5.2.3. Model Construction Workflow

Open the Model Builder in ArcGIS to set up an automated workflow. Apply the Inverse Distance Weighting (IDW) tool to the coefficient fields and residuals for each variable (7 variables), performing interpolation to generate coefficient surfaces.

Inverse Distance Weighting (IDW): A spatial interpolation method based on distance, with the core principle that "closer points have greater influence." It will approximate values at points where they are not known by giving more weight to their neighbors. More specifically, the method assigns weights based on the distance between the known data points and the point at which the data is being interpolated, with the closer points contributing a greater weight to the interpolated data point.Calculate the base (current) suitability, using the Model Builder in ArcGIS and excluding precipitation. The aim is to provide a static baseline component which is independent of precipitation scenarios so that the precipitation changes can be dynamically overlain.

Add a "Raster Calculator" tool. The formula is as follows:

Base Suitability = Residual + (Coeff_podu * Raster_podu) + (Coeff_poxiang * Raster_poxiang) + (Coeff_dan * Raster_dan) + (Coeff_ph * Raster_ph) + (Coeff_niantu * Raster_niantu) + (Coeff_youjizhi * Raster_youjizhi)

Note: Precipitation is not included in this step.

5.3. Prediction of Cultivated Land Distribution under Diverse Scenarios

A raster calculator is incorporated to take precipitation scenario rasters as model parameters, enabling flexible selection of precipitation datasets corresponding to various future scenarios during model execution. The calculation formula is specified as follows:

Final Suitability=Baseline Suitability+(Coeff_Rain×Precipitation Scenario Raster) The natural breaks (Jenks) classification method is applied to reclassify the evaluation outputs, partitioning the suitability values into five tiers: highly suitable, moderately suitable, generally suitable, marginally unsuitable, and unsuitable.

Based on this classification, predictive maps of cultivated land distribution across China under distinct future scenarios are generated, as illustrated in the figure below.

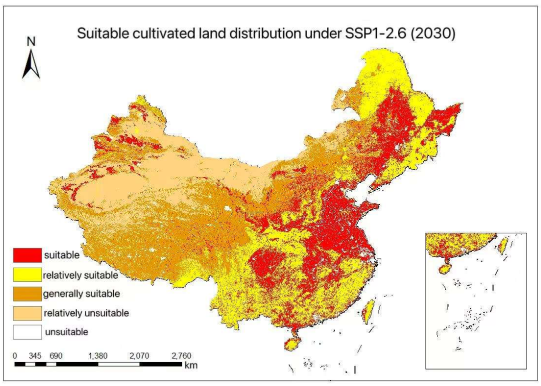

Figure 17. Suitable cultivated land distribution under SSP1-2.6 (2030)

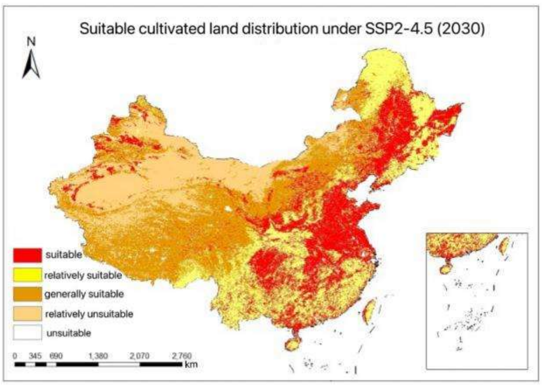

Figure 18. Suitable cultivated land distribution under SSP2-4.5 (2030)

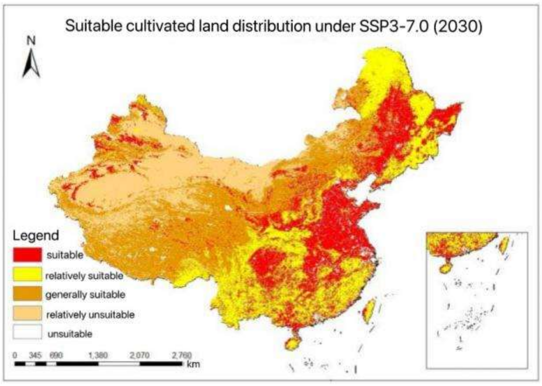

Figure 19. Suitable cultivated land distribution under SSP3-7.0 (2030)

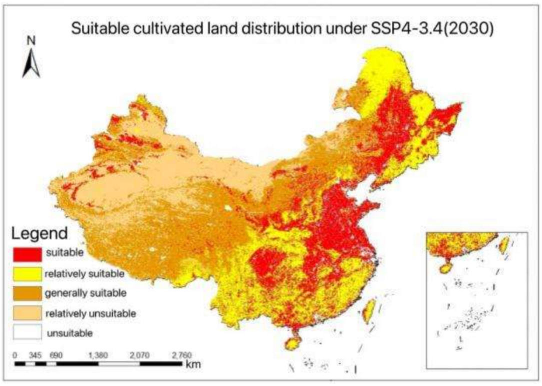

Figure 20. Suitable cultivated land distribution under SSP4-3.4 (2030)

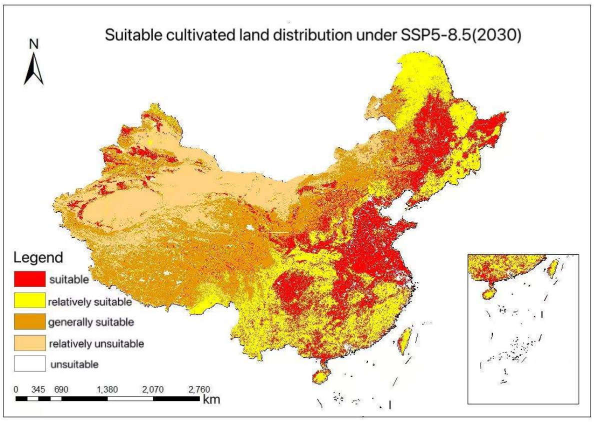

Figure 21. Suitable cultivated land distribution under SSP5-8.5 (2030)

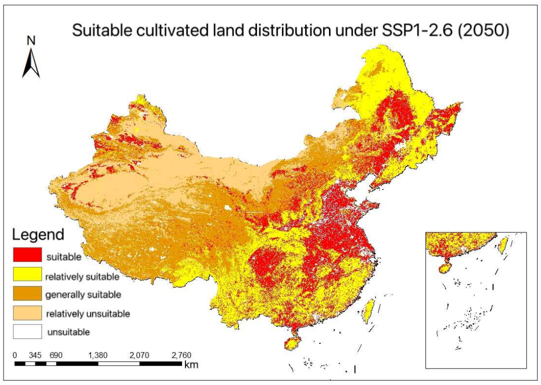

Figure 22. Suitable cultivated land distribution under SSP1-2.6 (2050)

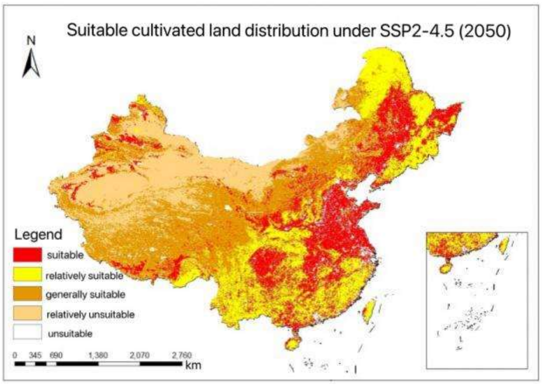

Figure 23. Suitable cultivated land distribution under SSP2-4.5 (2050)

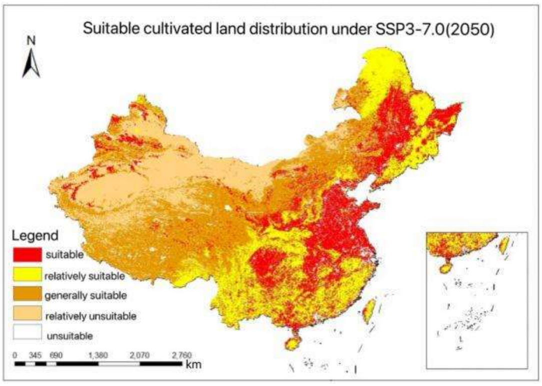

Figure 24. Suitable cultivated land distribution under SSP3-7.0 (2050)

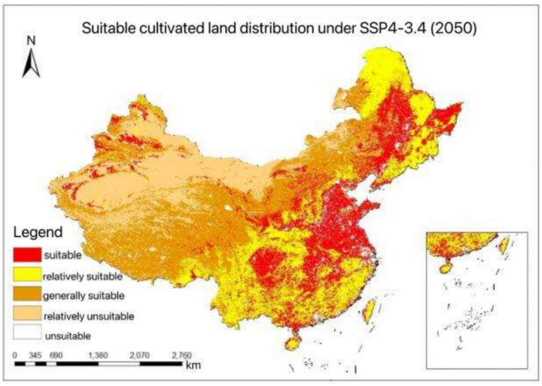

Figure 25. Suitable cultivated land distribution under SSP4-3.4 (2050)

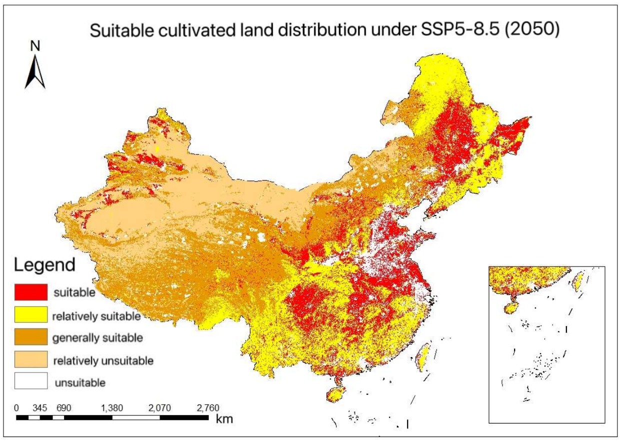

Figure 26. Suitable cultivated land distribution under SSP5-8.5 (2050)

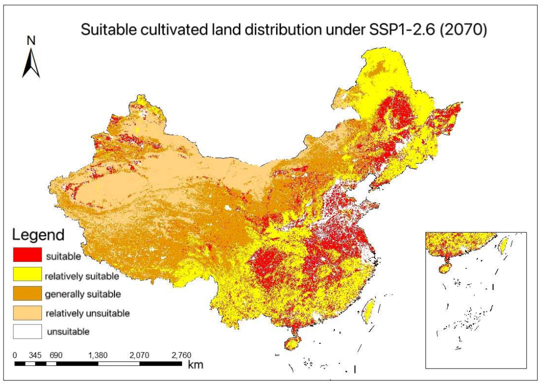

Figure 27. Suitable cultivated land distribution under SSP1-2.6 (2070)

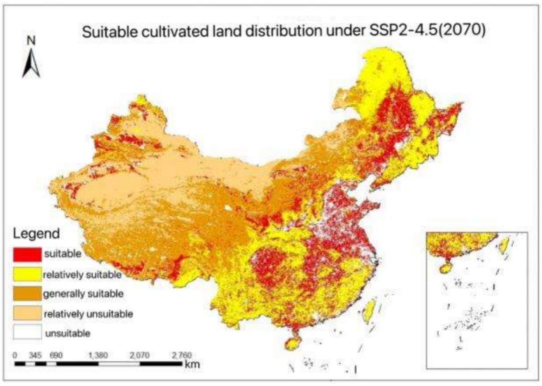

Figure 28. Suitable cultivated land distribution under SSP2-4.5 (2070)

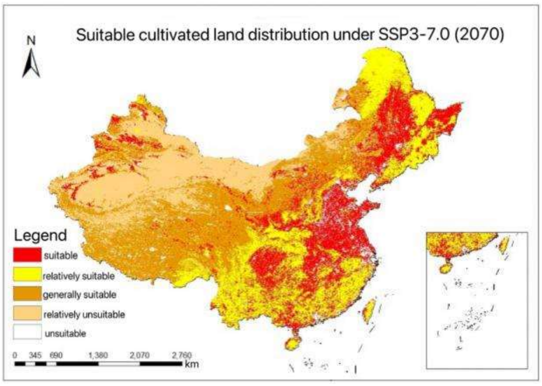

Figure 29. Suitable cultivated land distribution under SSP3-7.0 (2070)

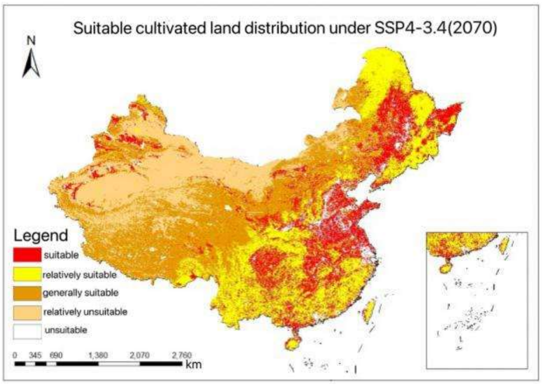

Figure 30. Suitable cultivated land distribution under SSP4-3.4 (2070)

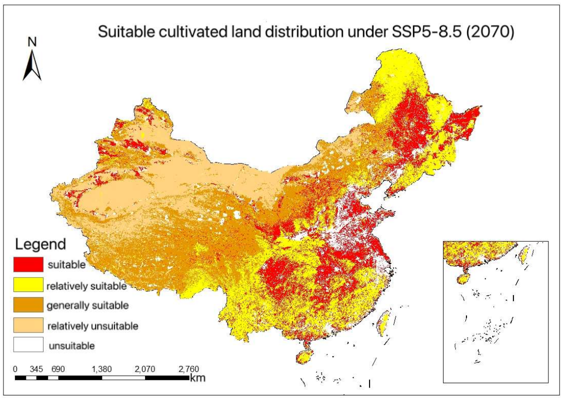

Figure 31. Suitable cultivated land distribution under SSP5-8.5 (2070)

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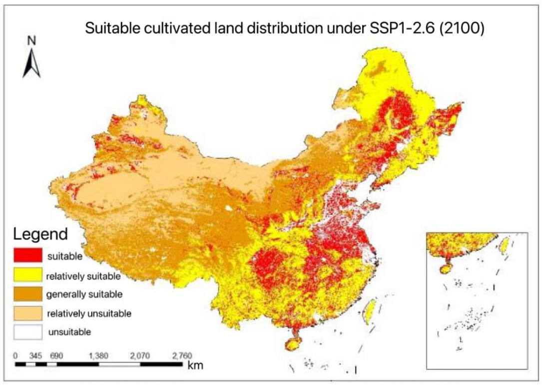

Figure 32. Suitable cultivated land distribution under SSP1-2.6 (2100)

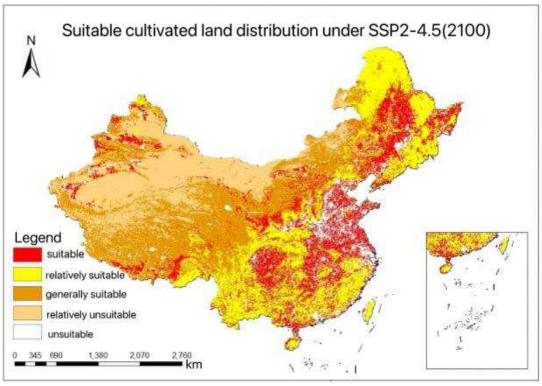

Figure 33. Suitable cultivated land distribution under SSP2-4.5 (2100)

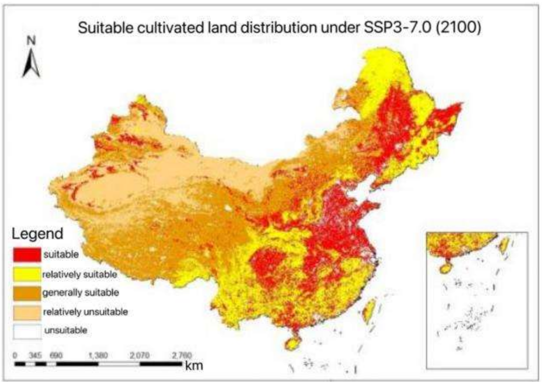

Figure 34. Suitable cultivated land distribution under SSP3-7.0 (2100)

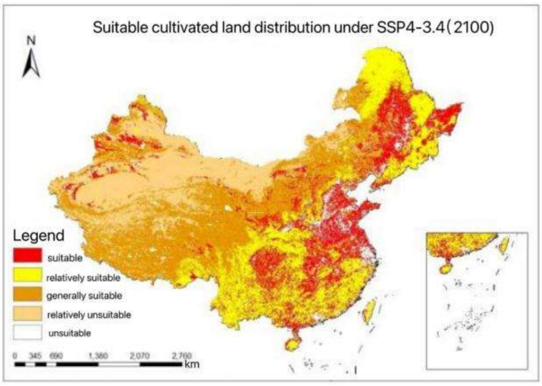

Figure 35. Suitable cultivated land distribution under SSP4-3.4 (2100)

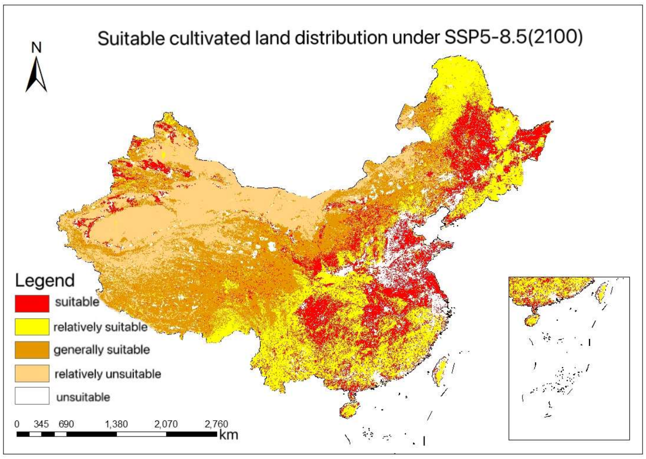

Figure 36. Suitable cultivated land distribution under SSP5-8.5 (2100)

5.4. Spatial Pattern Analysis of Suitable Cultivated Land

Current suitable cultivated land concentrates east of the Hu Huanyong Line, forming three contiguous core zones: the Northeast Plain (Sanjiang, Songnen and Liaohe Plain), North China Plain (Huang-Huai-Hai Plain) and Middle-Lower Yangtze Plain (Jianghan, Dongting, Poyang Lake Plain and Yangtze River Delta). The three zones feature fertile black soil, long cultivation history and superior hydrothermal conditions respectively, with dense and connected farmland patches. Cultivated land scatters across fragmented terrain in the Yunnan-Guizhou Plateau and Hengduan Mountains. Limited by water scarcity, farmland distributes sporadically in river valleys, oases and grassland belts of the Loess Plateau, Inner Mongolia Plateau and Qinghai-Tibet Plateau, accompanied by high ecological vulnerability. This baseline spatial pattern provides reference for multi-scenario future projections.

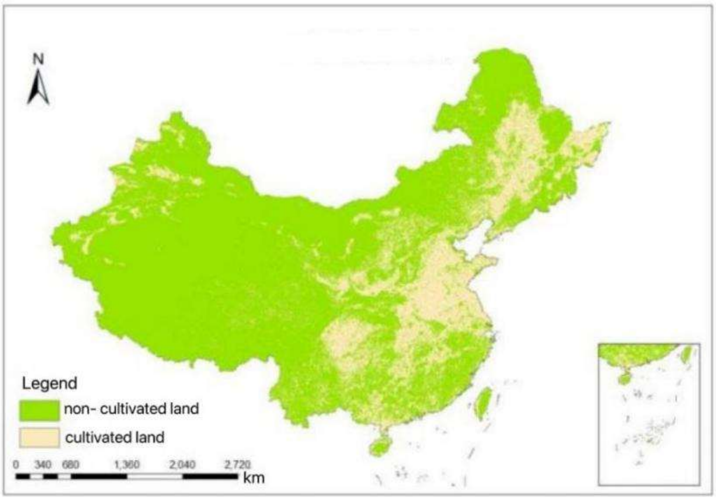

Figure 37. Spatial distribution of cultivated land in China (2023)

Five representative SSP-RCP pathways (SSP1-2.6, SSP2-4.5, SSP3-7.0, SSP4-3.4, SSP5-8.5) are adopted based on the Sixth IPCC Assessment Report. Projected precipitation spatial data under each pathway serve as core inputs to simulate spatial restructuring of suitable cultivated land until 2100.

Under the high-emission SSP5-8.5 scenario, traditional high-yield farming zones in southern China degrade remarkably, while northern gains remain limited and unstable. Degradation scope and magnitude in southern regions outweigh northern improvements, leading to continuous shrinkage and fragmentation of national highly suitable cultivated land. Southern degradation expands northward following clear chronological rules. By 2050, highly suitable farmland on the southern edge of the Middle-Lower Yangtze Plain and Jiangnan Hilly Region begins to fragment. Degradation extends deep into core grain-producing zones including the Jianghuai Area and Jianghan Plain by 2070 and 2100, with large areas of highly suitable land downgraded to generally suitable or marginally unsuitable grades. Northern regions respond inconsistently: the northern Northeast Plain and eastern Inner Mongolia Plateau expand suitable farming zones northward, yet intensified evapotranspiration causes water deficit in northern North China Plain and Loess Plateau, restraining local cultivation suitability. Mutual offset between northern gains and losses cannot compensate southern farmland degradation. In general, the SSP5-8.5 pathway creates severe risks for China’s suitable cultivated land resources, forcing profound spatial readjustment and threatening agricultural production capacity and stability.

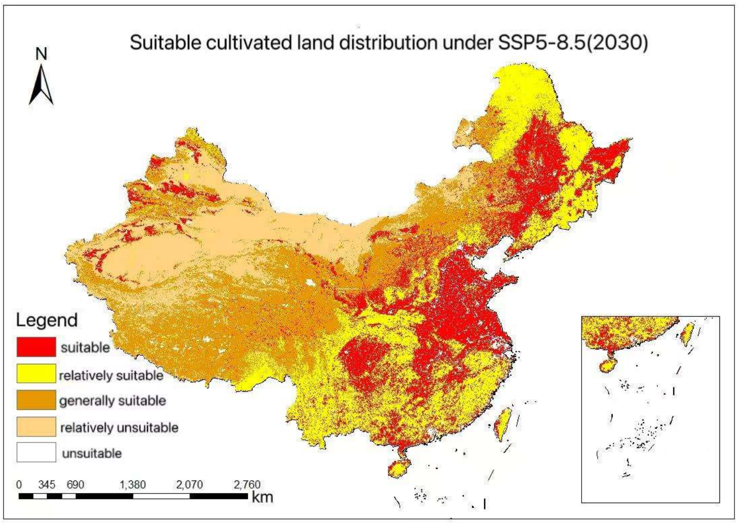

Figure 38. Suitable cultivated land distribution under SSP5-8.5 (2030)

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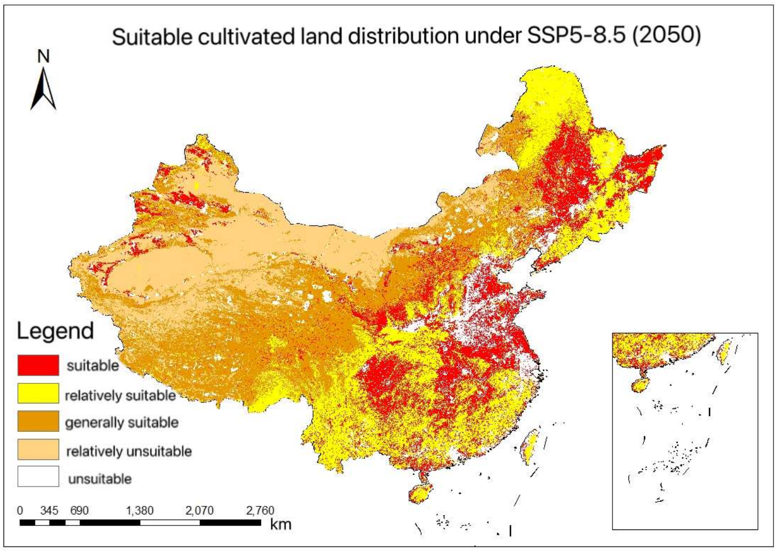

Figure 39. Suitable cultivated land distribution under SSP5-8.5 (2050)

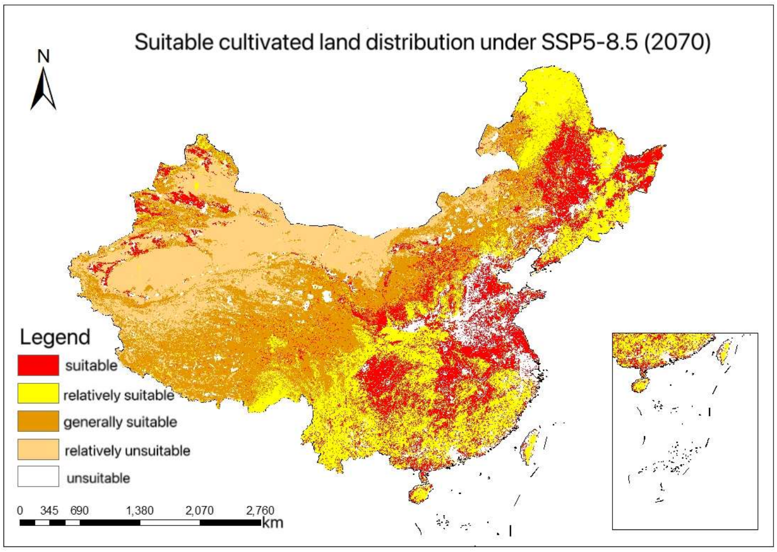

Figure 40. Suitable cultivated land distribution under SSP5-8.5 (2070)

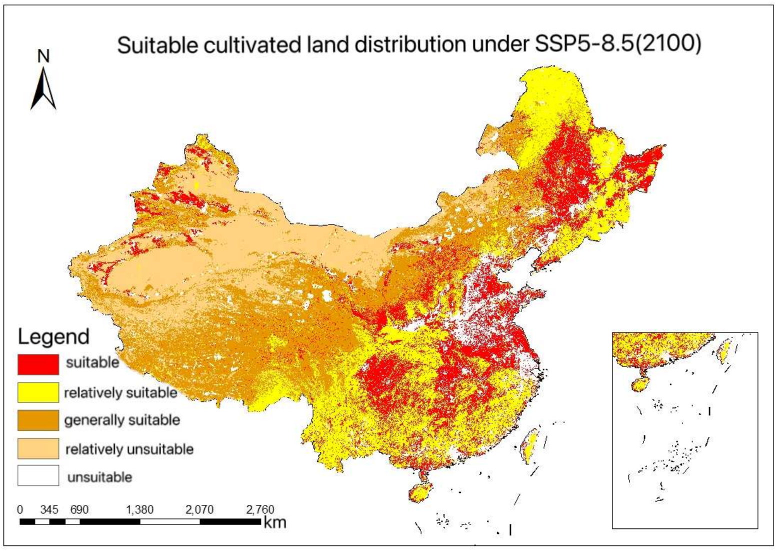

Figure 41. Suitable cultivated land distribution under SSP5-8.5 (2100)

Under the strong emission-reduction SSP1-2.6 scenario, climate disturbance is effectively controlled, and core southern farming zones maintain stable suitability. From 2030 to 2100, highly and moderately suitable cultivated land in the Middle-Lower Yangtze Plain and Jiangnan Hilly Region remains continuous and intact without fragmentation observed under high-forcing scenarios. Northern farmland expansion follows a sustainable and steady mode. The northward expansion of the northern Northeast Plain proceeds at a slower and more stable pace, and newly converted land stays at generally or moderately suitable grades. The two scenarios show opposite spatial patterns by 2100. SSP1-2.6 sustains an intact system of high-suitability farmland consistent with current layout, while SSP5-8.5 features extensive southern degradation and fragmented northern gains. This contrast proves active carbon mitigation and sustainable development deliver critical protection for agricultural resources and reduce long-term climate risks of farming systems.

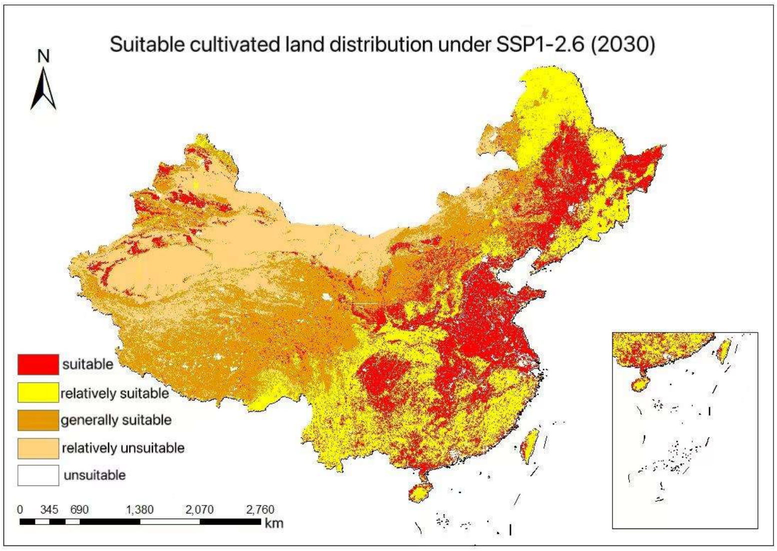

Figure 42. Suitable cultivated land distribution under SSP1-2.6 (2030)

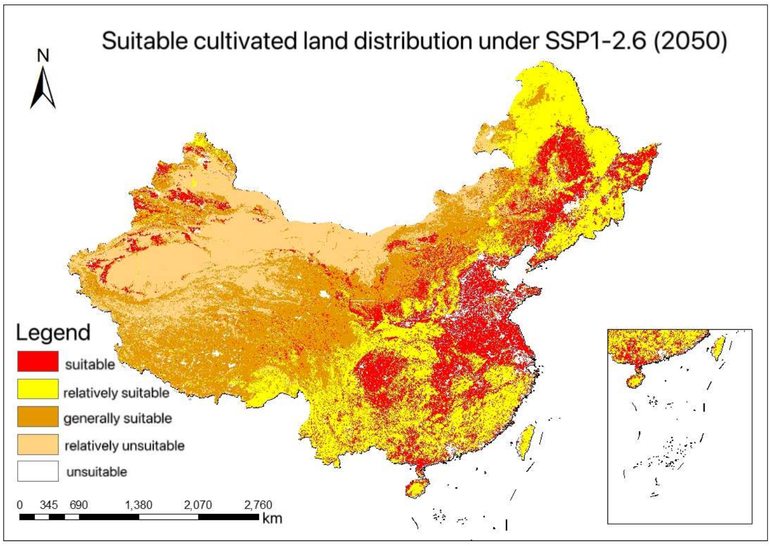

Figure 43. Suitable cultivated land distribution under SSP1-2.6 (2050)

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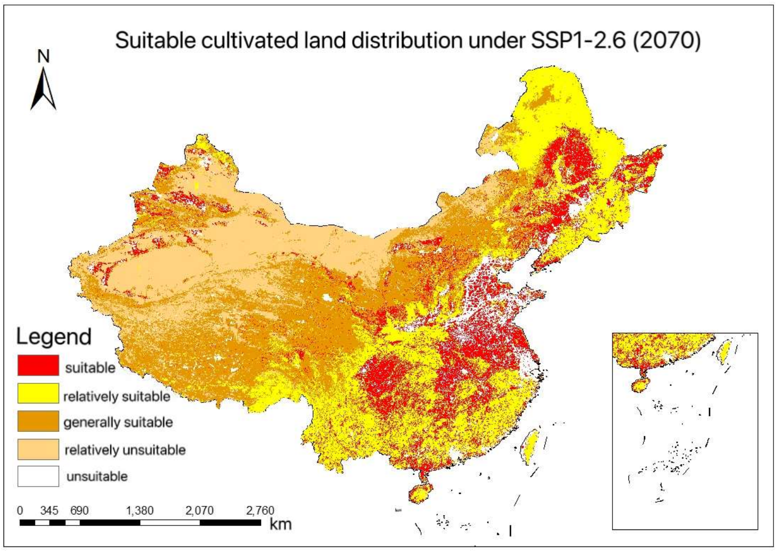

Figure 44. Suitable cultivated land distribution under SSP1-2.6 (2070)

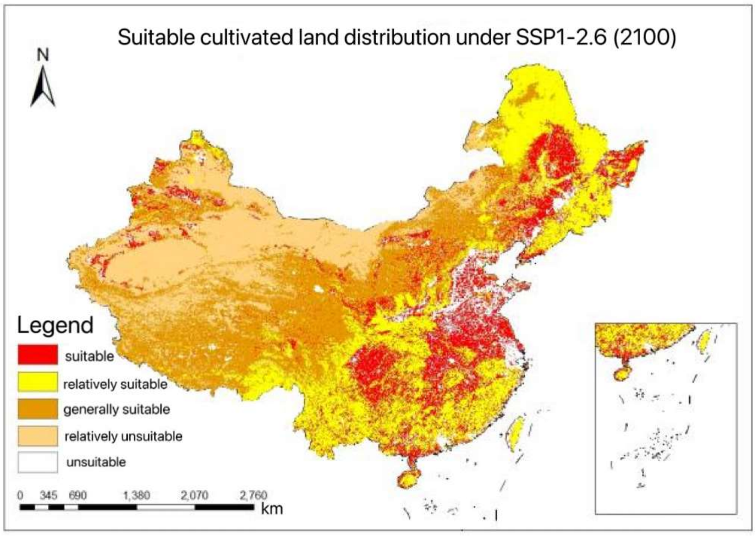

Figure 45. Suitable cultivated land distribution under SSP1-2.6 (2100)

5.5. Potential Classification of Suitable Cultivated Land and Targeted Management Strategies

Five-level suitability evaluation results are reclassified into three comprehensive potential grades to support territorial spatial planning, with corresponding management strategies proposed.High-potential zones (highly suitable and moderately suitable land): Mainly cover the Northeast Plain, North China Plain, Jianghuai Region and the main body of the Middle-Lower Yangtze Plain. These areas shall be designated as core permanent basic farmland with the strictest protection rules. Authorities should construct high-standard farmland, implement black soil conservation tillage and upgrade water conservancy infrastructure.Medium-potential zones (generally suitable land): Surround high-potential zones, covering the western Northeast Plain, piedmont transition zones of North China Plain, southern Loess Plateau, southern hilly areas and intermountain basins in southwest China. These regions serve as strategic buffer zones combining adaptive management and engineering improvement. Local governments shall promote water-saving irrigation, slope terracing and soil remediation.Low-potential zones (marginally unsuitable and unsuitable land): Concentrate on arid inland northwest China, alpine Qinghai-Tibet Plateau, southern rocky desert hills and ecologically fragile marginal zones. Ecological protection shall be prioritized, with large-scale grain-for-green programs and wind-break sand-fixation restoration projects.

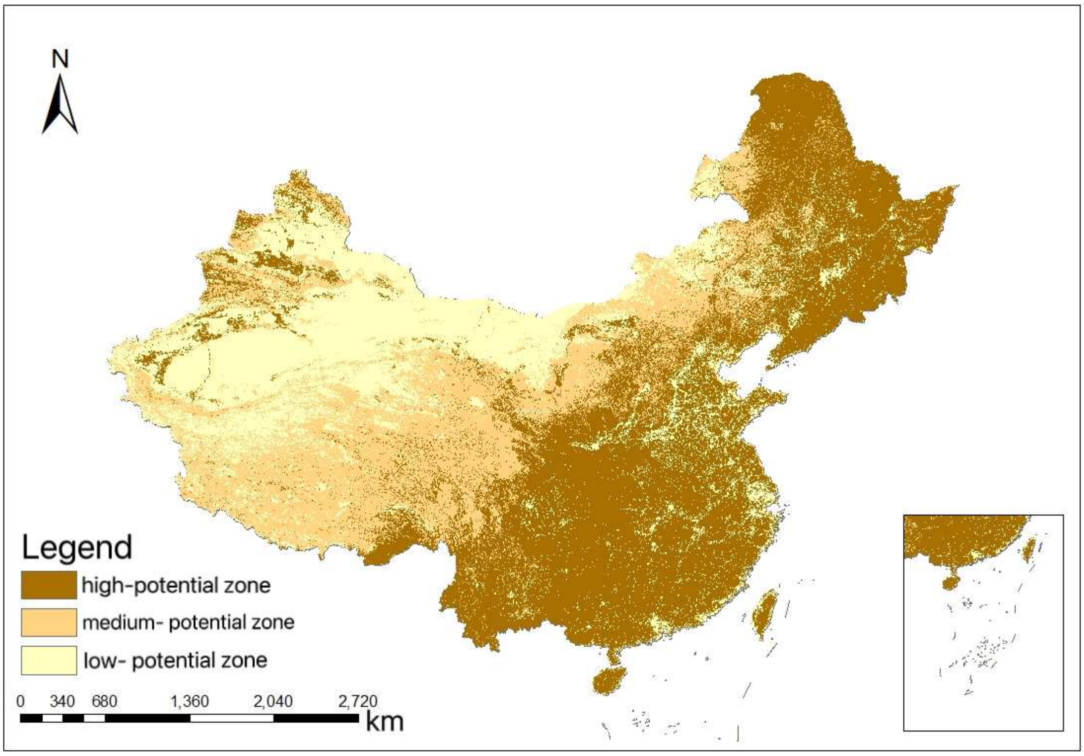

Figure 46. Potential classification map of cultivated land

5.6. Area Estimation and Spatial Distribution of Newly Added Suitable Cultivated Land

Based on multi-scenario simulation results, this study further quantifies and identifies the extent and spatial distribution of newly suitable arable land under different climate scenarios. In terms of area change, under the SSP1-2.6 scenario, the total national area of suitable arable land is projected to increase by approximately 126,000 square kilometers (a 2.1% rise) by 2100 compared to the 2023 baseline, with northern regions contributing about 85% of the new area. Under the SSP5-8.5 scenario, due to significant degradation in southern regions and limited gains in the north, the total area is expected to decrease by around 84,000 square kilometers (a 1.4% decline). For other scenarios, area changes fall between these two extremes, characterized by "expansion in the north, contraction in the south, slight overall increase, or near stability."

Newly suitable arable land is primarily concentrated in three types of regions: the expansion zone along the northern edge of the Northeast Plain (including northern Heihe and Yichun in Heilongjiang, and the eastern foothills of the Greater Khingan Range, totaling about 58,000 square kilometers); the suitable cultivation belt in eastern Inner Mongolia Plateau (southeastern Hulunbuir grassland, Xing'an League, and eastern parts of Xilingol League, about 43,000 square kilometers); and the northern Loess Plateau and marginal areas of northwest oases (northern Yulin in northern Shaanxi, central Ningxia, and the eastern section of Gansu's Hexi Corridor, about 25,000 square kilometers). Spatially, the newly suitable arable land exhibits characteristics of "northward expansion, westward advancement, and contiguous development": a continuous corridor forms from the Northeast Plain through the Inner Mongolia Plateau to the Loess Plateau, serving as a core axis; scattered yet relatively concentrated expansions emerge at the margins of northwest oases; and new arable land often borders existing farmland, merging into larger contiguous farming zones that facilitate large-scale operations and mechanized farming.

6. Conclusion and Policy Implications

6.1. Main Conclusion

This study explores variations of China's suitable cultivated land under the northward precipitation shift based on multi-source data and multi-scenario climate simulation, drawing three core conclusions:

(1) Precipitation acts as the dominant positive driving factor for cultivated land suitability. Better rainfall results in the conversion of the semi-arid marginal land in the north to become productive farmland while heavy rainfall causes soil erosion, soil waterlogging, and secondary soil salinization.

(2) The suitable areas of cultivated land vary differently with the scenarios. By 2100, in the high-emission SSP5-8.5 pathway, southern high-yield farmland shifts northward to become degraded and extends to core grain regions such as the Jianghan Plain. The rise of evapotranspiration results in the decrease of the total amount of high-suitability farmland in the northern part of North China Plain and Loess Plateau due to water shortage. For the low-emission SSP1-2.6 pathway, the core farming areas in the south stay stable, while in the north the land expansion is moderate, resulting in a spatial structure that is largely similar to the current one.

(3) Stable foundations for food security exist in the high potential zones around three major plains; strategic buffers and ecological conservation in low potential zones. There are two sensitive belts which need special risk prevention: Drought-prone northern fragile zones (from the Yanshan Piedmont to western Liaoning) and waterlogging-prone southern transition zones (from the Middle-Lower Yangtze Plain to Jiangnan Hilly Region). The appropriateness of such belts varies greatly with climate scenarios.

6.2. Policy Suggestions and Agricultural Planning Inspirations

The high-potential zones in the three major plains are to be identified as core permanent basic farmland for strict protection. Stable grain yield is ensured by construction of farmland with high standard and improvement of water conservancy.In medium-potential zones, a mixed approach of adaptive management and engineering improvements is implemented. In the north, water-saving irrigation technology is promoted and encouraged, and in the south, slope terracing, soil remediation, and crop planting structure are flexibly adjusted.Low-potential zones will take the principle of ecological priority and will carry out restoration projects with grain-for-green and sand-fixation; no blind reclaiming of fragile land will be allowed.Northern drought sensitive belts and southern waterlogging sensitive belts shall develop comprehensive monitoring system on precipitation and soil moisture, and set up climate risk early warning platforms. Improved drainage and irrigation infrastructure and stress-tolerant crop varieties reduce climate hazards.Agricultural policies shall coordinate with national carbon peaking and carbon neutrality goals. Authorities encourage straw return and organic fertilizer substitution, limit over-extraction of groundwater in northern irrigation zones, and guide agricultural systems toward sustainable climate-adaptive pathways.

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