MULTI-SCENARIO SIMULATION OF LAND USE SUITABILITY FOR URBAN EXPANSION BASED ON MARKOV-FLUS MODEL

by

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The ongoing discord between population growth and available land resources poses significant challenges to the sustainable development of human settlements in Guangdong Province. Multi-scenario simulation of land use oriented to the suitable human settlements is essential for the spatial optimization of land use and improvement of human settlements suitability. Five scenarios were established, each designed to assess different levels of suitability demands. The coupled Markov-FLUS model was employed to simulate land use in Guangdong Province in 2030. The simulation results indicated that the proportions of production, living, and ecological land areas were more co-ordinated under the comprehensive space optimization scenario. In comparison with the standard business-as-usual scenario, the cropland area exhibited an increase in major grain-producing areas, thereby facilitating the construction of high standard cropland. Concurrently, there has been an increase in ecological land in the central cities of the Pearl River Delta and the surrounding regions. This initiative has been demonstrated to enhance the improvement of the ecological environment and human settlements. In comparison with the living space preference scenario, the newly-added construction land increased in eastern and western regions, which was consistent with the requirements of optimizing urban space in Guangdong province. A comparative analysis reveals that spatial configurations within the comprehensive space optimization scenario exhibit enhanced rationality in comparison to alternative scenarios. The land use strategy employed in this scenario proved to be the optimal solution for the conflict between population and land. The findings of this study have the potential to furnish decision-support resources for the future enhancement of land use and the development of human settlements.

Key words: *suitability, land use, multi-scenario simulation, FLUS model*

Introduction

According to Human Development Report 2020 (United Nations Development Program, New York, 2020), a suitable human settlement is defined as a fundamental environment in which people gather and live [1]. Land resources are fundamental components of human settlements, providing sustenance, shelter, and ecological services, among other crucial functions. Land use has undergone significant transformations on a global scale in recent decades, precipitated by rapid population and socioeconomic growth [2, 3]. As the second largest

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economy in the world, China has long suffered from the challenges of tightening land resource constraints and intensifying land use conflicts [4]. For instance, the per capita cropland area in China was less than 40% of the global average [5]. This figure has decreased significantly as a result of increased construction [6]. Furthermore, the average annual growth rate of urban land in China was found to exceed that of population growth from 2000 to 2017 [7]. This phenomenon has been observed to exacerbate existing land use conflicts and pose a threat to the economic, social, and ecological benefits that are crucial for sustainable development. Consequently, the employment of suitability-oriented land use simulation is imperative for the optimization of spatial planning and the achievement of sustainable development of human settlements.

In order to manage limited land and promote sustainable development in an efficient manner, it is critical to reasonably predict and simulate land use patterns under possible future scenarios [8, 9]. Prior studies have focused extensively on the phenomenon of urban land sprawl. For instance, Talkhabi *et al.* [10] examined the correlation between urban sprawl and population change in the Tehran Metropolitan Region. Liang *et al.* [11] simulated urban growth boundaries under six designed scenarios, including the baseline, economic zoning development, sustainable urban development, excessive urban growth, and other scenarios. Rapid urban sprawl represents a significant challenge for developing countries, as it has a detrimental effect on cropland and ecological land. A mounting body of literature has emerged that is centered on the spatial optimization of cropland and ecological land [12, 13]. Ma and Wang [14] simulated the distribution of ecological space in the Wuhan Metropolitan Area in 2035 under five scenarios. Conventionally, the field of land use research has centered on the spatial optimization of specific land types. However, there is a paucity of studies that have considered comprehensive optimization for different land use types. Furthermore, the profound transformation of rural settlements was frequently overlooked in conventional land use research. The spatial optimization of production, living, and ecological space plays a vital role in resolving conflicts among land uses [15]. It is imperative to ascertain a mutually beneficial strategy that encompasses the preservation of cropland, the development of urban and rural settlements, and the implementation of ecological conservation measures. Achieving suitable human settlements is contingent upon the successful implementation of such a strategy. Therefore, given the full consideration of land use demand for suitable human settlements, the multi-scenario simulation and comparison of different land use types renders the prediction results more objective and rational in this study.

Guangdong province has emerged as the preeminent economic entity within China's Yangtze River economic belt, a position further solidified by its leading ranking in both the total GDP and population among all provinces in 2022. Concurrently, Guangdong province has witnessed an ongoing and escalating discord among cropland, urban land, and ecological land, which jeopardize the quality of human life and the pursuit of sustainable development. The objective of this study was to simulate the suitability-oriented land use under multi-scenarios in Guangdong province using the Markov and FLUS model. The results of this study have the potential to provide decision-making support for the resolution of conflicts among production, living, and ecological land in Guangdong Province. Furthermore, they can offer a scientific basis for the development of suitable human settlements.

Data and methodology

Study area

Guangdong Province is located in the southernmost part of China. The topography of the province is characterized by high terrain in the northern regions and low terrain in the southern regions. The region is comprised of 21 cities, which are divided into four regions: the Pearl River Delta (PRD), Eastern Guangdong (EG), Western Guangdong (WG), and Northern Guangdong (NG), fig. 1. Guangdong Province is characterized by a substantial population density, yet its per capita allocation of construction land is comparatively limited. In 2018, the population of permanent residents was 1.13 million, making it the largest in China. In comparison with the year 2010, the population increased by approximately 9.06 million individuals, exhibiting an average growth rate of 10.4‰. The urbanization rate was 70.7%, which was 11.1% higher than the national average. In 2018, the population density was 631 people per square kilometer, which is four times the national population density.

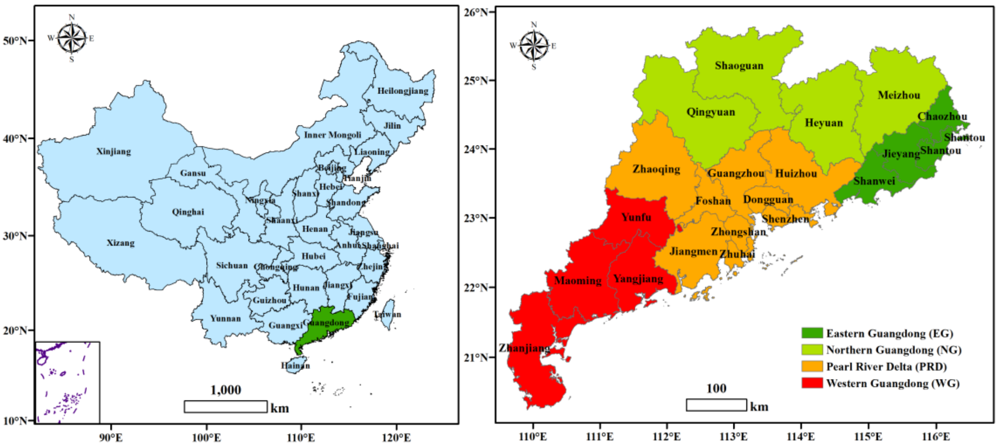

Figure 1. Location of Guangdong province and its 21 cities

Data sources

The digital elevation model is derived from a *geospatial data cloud* with a spatial resolution of 90 m × 90 m. The elevation, slope, and aspect are obtained using the ArcGIS analysis tool. The interpretation of land use data from remote sensing images is conducted with a spatial resolution of 100 m × 100 m. The remote sensing data is provided by the Resource and Environmental Science Data Center of the Chinese Academy of Sciences. The geographical data pertaining to rivers, railways, highways, and residential areas is obtained from the National Geographic Information Resource Catalog Service System. The spatial distribution of population and economy is obtained from the Resource and Environmental Science Data Center of the Chinese Academy of Sciences. In order to reflect the demand for production, living, and ecological land, land types are reclassified into four types: production land (*i.e.*, cultivated land), living land (*i.e.*, urban land, rural residential area, and other construction lands), ecological land (*i.e.*, forest land, grassland, and water area), and unused land.

Methodology

Prediction of land scale using Markov model

The Markov chain model has been demonstrated to be an effective tool for predicting the land scale in subsequent periods, as evidenced by the analysis of two periods of land scale data. This paper utilizes a Markov chain model with a 5 years time interval to predict land scale demand in 2035. The model is informed by data on various land scales from 2015 and 2020.

Spatial simulation of land use using FLUS model

– Spatial distribution simulation of land use

The following steps are taken in the simulation process of land-bearing space layout based on cellular automata. First, the neighborhood weight coefficient, adaptive inertia coefficient, conversion cost matrix, and other parameters are set based on the probability distribution of land suitability. Then, the overall conversion probability of each cell is obtained. Next, the demand of each land type is set. Then, the restrictive area of mutual conversion of land types is set according to the development scenario. Finally, the land-bearing spatial pattern is simulated by the adaptive inertial competition mechanism selected by roulette.

At this stage, the primary parameters that must be determined include the neighborhood weight coefficient, the transformation cost matrix, the adaptive inertia coefficient-related parameters, and the restriction region. The neighborhood weight coefficient is indicative of the expansion intensity of each land type, reflecting the interaction between different land use types and different land use units within the neighborhood. The closer the value is to 1, the stronger the expansion ability of the land use type. In this study, the neighborhood size, designated as N, is set to 3×3, and the neighborhood weight coefficient is calculated based on the raster variation of each land use type in historical scenarios. The conversion cost matrix is a tool used to determine the financial implications of converting one land use type to another. The matrix utilizes a system of values ranging from 0 to 1, with 0 representing cases where conversion is not permitted and 1 representing cases where conversion is permitted.

The adaptive inertia coefficient is a critical element in this system, as it facilitates the adjustment of the number of land types through an iterative method. The calculation formula for the adaptive inertia coefficient is:

$$I_k^t = \begin{cases} I_k^{t-1}, & \text{if} \quad \left|D_k^{t-1}\right| \le \left|D_k^{t-2}\right| \\ I_k^{t-1}\dfrac{D_k^{t-2}}{D_k^{t-1}}, & \text{if} \quad D_k^{t-1} < D_k^{t-2} < 0 \\ I_k^{t-1}\dfrac{D_k^{t-1}}{D_k^{t-2}}, & \text{if} \quad 0 < D_k^{t-2} < D_k^{t-1} \end{cases} \tag{1}$$

where I_k^t is the adaptive inertia coefficient of land use type k at iteration time t and D_k^{t-1}– the difference between land use demand and allocated area at t – 1. The overall transition probability of each cell was calculated by combining the development probability of terrain suitability, intercellular neighborhood influence factor, adaptive inertia coefficient and conversion cost.

– Model accuracy verification

The model accuracy was verified using real land use data from 2015 and 2018 in this study. The overall accuracy (OA), Kappa, and figure of merit (FoM) coefficients were calculated to assess the model accuracy. The values of the OA and Kappa coefficients ranged from 0 to 1, with the FoM coefficient value generally less than 0.3. The majority of FoM coefficients fell within the range of 0.1 to 0.2. It was demonstrated that an increase in the value resulted in a corresponding increase in simulation accuracy.

Results

Multi-scenario simulation results

In light of the discord between various land uses and the demand for suitable human settlement development, a total of five scenarios have been identified and designated as follows. The following scenarios are to be considered: business as usual (BAU) scenario, production space preference (PP) scenario, living space preference (LP) scenario, ecological space preference (EP) scenario, and comprehensive space optimization (CO) scenario.

Business as usual scenario

The BAU scenario indicates that the regional land policy, population, and economic growth rate have remained relatively stable. The observed shift in land use represents a continuation of the prevailing trend of development. In accordance with the land use transfer probability matrix from 2015 to 2018, tab. 1, the Markov model is employed to forecast the raster cell values of each land use category in 2030. The reversibility of urban construction land is weak and cannot be converted into arable land. Rural settlements cannot be converted to grassland, and the conversion cost factor is 0. Conversely, unused land can be converted into urban land with a conversion cost factor of 1.

Table 1. Conversion probability between land use types between 2015 and 2018.

	Cropland	Forest	Grassland	Water	Urban land	Rural land	Other construction land	Unused land
Cropland	99.454	0.010	0.010	0.009	0.298	0.011	0.209	0.000
Forest	0.001	99.827	0.058	0.003	0.024	0.000	0.087	0.000
Grassland	0.001	0.865	98.565	0.015	0.330	0.008	0.217	0.000
Water	0.010	0.014	0.023	98.976	0.136	0.013	0.828	0.000
Urban land	0.000	0.004	0.000	0.021	99.866	0.018	0.092	0.000
Rural land	0.003	0.008	0.000	0.014	0.301	98.959	0.715	0.000
Other construction land	0.091	0.150	0.487	0.351	2.748	0.039	96.118	0.015
Unused land	0.000	0.000	0.000	0.000	0.000	0.000	1.582	98.418

Production space preference scenario

In scenarios where the priority is on cultivating land, emphasis is placed on preserving the area dedicated to agriculture and restricting the conversion of agricultural land to residential and ecological uses. This approach is intended to address the pressing concern of the rapid decline in agricultural land and enhance the viability and resilience of these areas.

In comparison with the benchmark scenario, the preference scenario of production land necessitates an augmentation in the probability of cultivated land transfer in, concurrent with a reduction in the probability of cultivated land transfer out, with the objective of enhancing the stability of cultivated land. In accordance with the stipulated target constraint of cultivated land area in the Land Plan, the probability of land transfer is subject to adjustment. Specifically, the probability of transferring cultivated land to forest land, grassland, and water area is set to zero. Additionally, the probability of transferring cultivated land to cities and other construction land is reduced from 0.30% and 0.21% in the base scenario to 0.22% and 0.15%. Concurrently, the probability of transferring unused land to cultivated land is increased to 0.16%. The conversion of cultivated land to ecological land is strictly forbidden. The financial implications associated with the transformation of cultivated land into forest land, grassland, and water bodies are designated as zero. Conversely, the transfer of unused land to arable land is permitted, with a conversion cost factor of one.

Living space preference scenario

In the context of preference living land, priority will be given to the constraint of urban, rural, and other construction land required for the future development of regional human settlements by the intensity of land development in the province. The demand for new construction land, attributable to population growth, will be met through the stock renewal of urban and rural land integration. According to the province's land development intensity control target in the *Land Plan*, the grid cells of new construction land in 2018~2030 shall not exceed 156380. According to the Population and Urbanization Rate Planning Values in the Population Development Plan of Guangdong Province (2017-2030) and the per capita construction land area of new cities and towns in the Urban and Rural Land Classification and Planning Construction Land Standards, the number of urban land grids in 2030 is predicted to be 747,899. The development of other construction land is guided by the prevailing trends from 2015 to 2018. The data set, which includes new construction land, urban land, and other construction land grids, was used to forecast the number of rural settlements in 2030.

Ecological space preference scenario

The water conservation area is regarded as an ecological land restriction area, primarily located in the hilly area of northwest and eastern Guangdong, with the objective of protecting the ecological integrity of major rivers and reservoirs. In accordance with the ecological land preference scenario, the conversion of land between cultivated, forest, grassland, and water areas is permitted. The transfer probability is maintained at the level of the benchmark scenario, and the conversion cost coefficient is set to 1. According to the land transfer probability matrix from 2010 to 2015, the conversion of unused land to water is permitted, with a conversion probability of 1.38%. In order to reflect the preference function of ecological land, the probability of transferring ecological land to construction land is set to 0, and the conversion cost coefficient to urban land is set to 0. Through the constraints of land transfer probability and conversion cost coefficient, the occupation of ecological land by urbanization development is reduced.

Comprehensive space optimization scenario

In the context of the comprehensive land use optimization scenario, priority is accorded to the cultivation of designated land, a commitment that aligns with the number of cultivated land cells delineated in the production preference scenario. This adjustment was necessitated by the potential inclusion of the green area of the park within the grassland category. Consequently, the per capita urban land area was reduced to 96.1 m^2 per person, and the new urban land area was adjusted to 150500 hectares. The prevailing hypothesis suggests that when the elastic coefficient of land and the population urbanization rate are equal to 1.12, these variables are in a state of harmony. The population change rate from 2018 to 2030 was used to predict the land urbanization rate. The grid number of rural settlements in 2030 was obtained by combining the amount of construction land grid under the living scenario. Then, the grid number of other construction land was obtained.

From the perspective of cultivated land protection, the probability of cultivated land transfer was reduced from 0.55% to 0.40% in the base scenario. It is imperative to augment the probability of transfer for other land types, to permit the conversion of unused land to cultivated land, and to reserve resources for cultivated land. From the perspective of optimizing urban and rural land use structure, the probability of rural settlements being transferred out increased from 1.04% in the benchmark scenario to 3.30%, primarily to urban land. This was achieved by promoting land use structural adjustment through the linkage between urban and rural land use increase and decrease. From the perspective of ecological land protection, the proportion of ecological land space and the urgency of regional human settlement environment development needs are considered. In this regard, priority is given to ensuring the water area, followed by grassland and forest land area. From the perspective of the conversion cost coefficient, alternative land use types are not converted to unused land, and the coefficient is thus equivalent to 0. Conversely, the conversion of unused land to cultivated land, water bodies, urban land, and other construction land is permitted, with a coefficient of 1.

Multi-scenario simulation results

Prediction results of land scale

The probability of land use transfer under multiple scenarios was determined using a Markov model, which was employed to calculate the number of rasters for each land use type in 2030 following four predictions, with a time step of three years, tab. 2. The conversion cost matrix under multiple scenarios was adjusted, and the FLUS model was used for spatial simulation. The final simulation value of the number of cells of each land use type in 2030 was obtained.

Table 2. Predicted values of land use types under different scenarios in 2030 and actual value in 2018

	Cropland	Forest	Grassland	Water	Urban land	Rural land	Other construction land	Unused land
Annual value in 2018	4253336	10748906	782103	803158	591154	422099	315949	11891
BAU scenario	4163329	10705700	771543	779351	705518	408368	383431	11356
PP scenario	4185678	10704100	769874	777894	692220	408365	379110	11355
LP scenario	4174160	10705900	772015	779841	747899	342170	395513	11098
EP scenario	4162070	10753556	788121	810003	677948	407504	318116	11278
CO scenario	4185678	10704306	770156	778537	741635	371013	366670	10601

Spatial simulation results of land use

The 2018 land use raster data was utilized as the initial value, and the predicted value of the 2021, 2024, 2027, and 2030 land use grid Markov model was employed as the future raster quantity value. The FLUS model was implemented for spatial simulation, and the land-bearing spatial pattern under multiple scenarios in 2030 was analyzed, fig. 2.

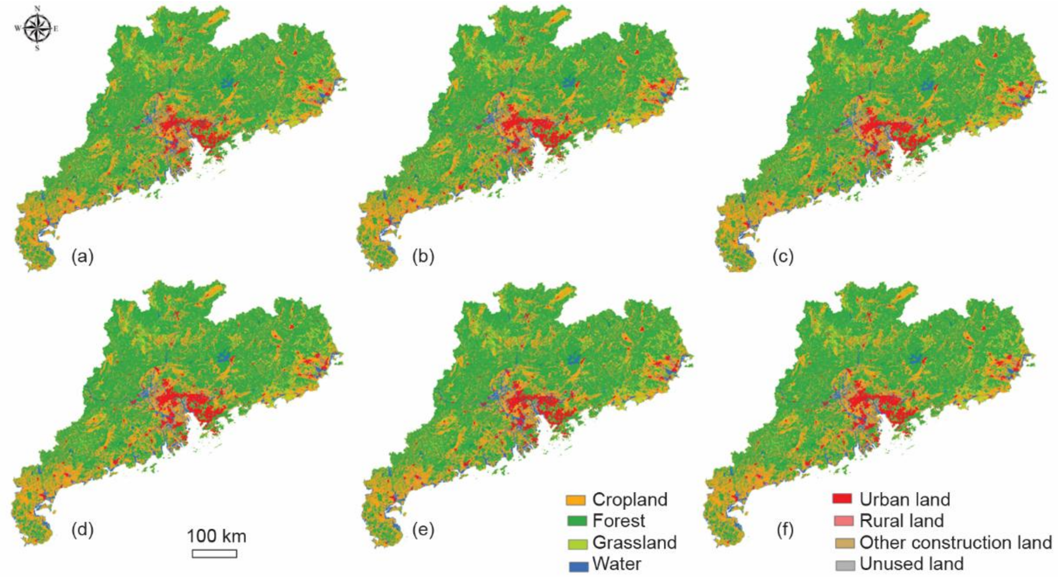

Figure 2. Simulation results of land carrying capacity space under multiple scenarios in 2030; (a) actual land use in 2018, (b) BAU scenario in 2030, (c) PP scenario in 2030, (d) LP scenario in 2030, (e) EP scenario in 2030, and (f) CO scenario in 2030

As illustrated in fig. 2(b), compared with 2018, the number of raster cells for production land in the province is projected to decrease by 0.53% in 2030. Construction land and urban land in all cities have exhibited an expansion trend. From 2018 to 2030, the rate of construction land growth will be most rapid in the central urban area of the Pearl River Delta, with an expected increase exceeding 4%. A substantial expansion trend is projected from the aforementioned area to peripheral regions. In contrast, the growth ratio in northern and eastern Guangdong, which are economically underdeveloped and characterized by a comparatively low urbanization rate, is expected to be more modest. The area of rural settlements has undergone a gradual decline, and the co-ordinated development of population and land urbanization has not been achieved. In accordance with the prevailing trend of historical scenarios, the expansion of urban land is proceeding at an accelerated pace. The proportion of living land is the primary concern, and the trend of reducing cultivated land and ecological land is proving to be challenging to reverse. Furthermore, the lack of an effective linkage between increasing urban and rural land use exacerbates the prevailing issue of unreasonable urban and rural land use structures. A comparison of the spatial reform requirements of production, living, and ecological land use in the Land Plan with the current land use structure reveals the urgent need for optimization and adjustment.

As illustrated in fig. 2(c), when compared with the year 2018, the quantity of raster cells designated for production land within the province in the year 2030 diminished by 0.37%. This decline represents an augmentation of 0.13% in comparison with the base scenario, thereby demonstrating an enhancement in the stability of cultivated land. As demonstrated in fig. 2(a), the arable land grid alterations at the urban scale reveal a substantial decline in cultivated land in Foshan (–20512), Guangzhou (–19504), and Dongguan (–13630). This decline is primarily attributed to the substantial demand for cultivated land that has been allocated to the expansion of construction land and the inadequate replenishment of reserve arable land. Consequently, achieving a balance in cultivated land resources in regions experiencing accelerated urbanization has proven to be challenging. Zhanjiang (+4196), Qingyuan (+2861), Shaoguan (+1684), and other cities have achieved incremental development of arable land resources, which plays an important role in ensuring the area and quality of cultivated land and even food security. It is noteworthy that under the production land preference scenario, ecological land exhibited only a marginal increase in Zhuhai and Zhaoqing, while it demonstrated a substantial downward trend in the remaining 19 cities. This phenomenon indicates that the process of urbanization is occurring at the expense of ecological land, as the probability of converting cultivated land to construction land is reduced.

In scenarios of preference living land, the method of linking the increase and decrease of urban and rural construction land is adopted to accelerate the integration of urban and rural areas. As illustrated in fig. 2(b), in comparison with 2018, the augmentation in living land within the province in 2030, with subsequent increases in the eastern Guangdong region. This region has undergone a spatial expansion from the central city to the periphery, exhibiting the most substantial increase in urban land use in terms of land type. When compared with other scenarios, under the preference scenario of living land, urban land space accounted for the highest proportion (4.16%), and rural settlement space accounted for the smallest proportion (1.91%).

In comparison with alternative scenarios, the ecological preference scenario has yielded a modest positive transformation in the development of ecological land, marked by an increase of 0.09% over the year 2018. As illustrated in fig. 2(e), from the perspective of spatial distribution pattern, the ecological land of 12 cities in Guangdong Province has achieved positive growth. With the exception of Huizhou, the cities within the Pearl River Delta have undergone significant ecological land growth, with Zhaoqing demonstrating the most pronounced increase in ecological land.

In the context of comprehensive land use optimization illustrated in fig. 2(f), the following measures are proposed to promote the co-ordinated development of production, living, and ecological land.

Appropriate reduction of the probability of transfer of cultivated land to other uses.

Adjustment of the probability of urban and rural land conversion to co-ordinate land urbanization with population urbanization

Control of the transfer of ecological space land In the comprehensive land use optimization scenario, production land accounted for 23.35%, living land accounted for 8.24%, and ecological land accounted for 68.36%. A comparison of the present study's results with the benchmark scenario reveals that the proportion of production land increased by 0.13%, the proportion of living land decreased by 0.11%, and the proportion of production, living, and ecological land was relatively balanced.

Conclusion

Five land use scenarios were established, including the BAU scenario, production, living, ecological space preference, and comprehensive space optimization scenarios. Using coupled Markov and FLUS models, the simulation was conducted to predict the suitability of land use in Guangdong Province in 2030. The cropland exhibited the least reduction under the PP scenario. Under the LP scenario, the proportion of urban land was the highest (4.16%) whereas that of rural areas was the lowest (1.91%). Under the EP scenario, the forest, grassland, and water areas exhibited a favorable transformation. Under the CO scenario, the distribution of production, living, and ecological land was comparatively balanced, as opposed to other scenarios. It demonstrated the capacity to satisfy the diverse criteria associated with cropland protection, land urbanization, and ecological preservation in Guangdong Province. The spatial patterns of land use exhibited significant variation under five distinct scenarios. A comparison of the BAU scenario with the CO scenario reveals that the cropland area in major grain-producing areas, including Qingyuan, Heyuan, and Meizhou, exhibited an increase under the CO scenario. This initiative has contributed to the development of high-quality farmland in key grain-producing regions. The augmentation of ecological land was obtained in the central area of PRD and its peripheral districts and counties, such as Jiangmen, Huizhou, and so on. The initiative was designed to promote the improvement of ecology and the living environment. In contrast with the LP scenario, the recently incorporated construction land exhibited a decline in central regions, including Foshan and Guangzhou. A rise in the index was observed in eastern and western Guangdong, including the municipalities of Maoming, Zhanjiang, and Jieyang. This approach aligns with the principles of urban planning as outlined in the Guangdong Province's guidelines.

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References

[1] Luo, X., *et al.,* Suitability of Human Settlements in Mountainous Areas from the Perspective of Ventilation: A Case Study of the Main Urban Area of Chongqing, *J. Clean. Prod., 310* (2021), 127467

[2] Xu, Z. C., *et al.,* Assessing Progress towards Sustainable Development over Space and Time, *Nature, 577* (2020), Jan., pp. 74-78

[3] Schungel, J., *et al.,* Effects of Initialization of a Global Land-Use Model on Simulated Land Change and Loss of Natural Vegetation, *Environ Moodell Softw., 148* (2022), 105287

[4] Fu, J. Y., *et al.,* Sustainable Land Use Diagnosis Based on the Perspective of Production-Living-Ecological Spaces in China, *Land Use Policy, 122* (2022), 106386

[5] Zhou, Y., *et al.,* Cultivated Land Loss and Construction Land Expansion in China: Evidence from National Land Surveys in 1996, 2009 and 2019, *Land Use Policy, 125* (2022), 106496

[6] Liu, S. C., *et al.,* Relationship between Urban Construction Land Expansion and Population/Economic Growth in Liaoning Province, China, *Land Use Policy, 99* (2020), 105022

[7] ***, Ministry of Natural Resources, P. Main Data Bulletin of the Third National Land Survey. Available online: http://www.mnr.gov.cn/dt/ywbb/202108/t20210826_2678340.html (accessed on 28 August 2021)

[8] Nourqolipour, R., *et al.,* A GIS-Based Model to Analyze the Spatial and Temporal Development of Oil Palm Land Use in Kuala Langat District, *Malaysia. Environ. Earth Sci., 73* (2015), 4, pp. 1687-1700

[9] Yang, Y. Y., *et al.*, Scenario Simulation of Land System Change in the Beijing-Tianjin-Hebei Region, *Land Use Policy, 96* (2020), 104677

[10] Talkhabi, H., *et al.*, Spatial and Temporal Population Change in the Tehran Metropolitan Region and its Consequences on Urban Decline and Sprawl, *Ecol. Inform., 70* (2022), 101731

[11] Liang, X., *et al.*, Delineating Multi-Scenario Urban Growth Boundaries with a CA-Based FLUS Model and Morphological Method, *Landscape and Urban Planning, 177* (2018), Sept., pp. 47-63

[12] Jiang, C., Song, W., Degree of Abandoned Cropland and Socioeconomic Impact Factors in China: Multi-Level Analysis Model Based on the Farmer and District/County Levels, *Land, 11* (2022), 1, 8

[13] Liu, P. J., *et al.*, Land Use Optimization Research Based on FLUS Model and Ecosystem Services - Setting Jinan City as an Example, *Urban Clim., 40* (2021), 100984

[14] Ma, B., Wang, X., What is the Future of Ecological Space in Wuhan Metropolitan Area? A Multi-Scenario Simulation Based on Markov-FLUS, *Ecol. Indic., 141* (2022), 109124

[15] Fu, J. Y., *et al.*, Sustainable Land Use Diagnosis Based on the Perspective of Production-Living-Ecological Spaces in China, *Land Use Policy, 122* (2022), 106386

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