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Land suitability analysis of urban agriculture for different investment scenarios: Evidence from fuzhou of China

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ABSTRACT

Urban agriculture provides a new strategic idea for solving the problem of urban food demand. The main objective of this study is to develop a spatial model for land suitability evaluation of urban agricultural development under different investment demands (urban agriculture 1.0 and 2.0), based on prospect theory and using GIS and TOPSIS analysis techniques. As a whole, we have developed a land suitability evaluation system for urban agricultural development under different investment needs (urban agriculture 1.0 and 2.0). We constructed a land suitability evaluation system for urban agriculture including ecological environment, social demand and investment cost. The results of the land suitability analysis for urban agriculture 1.0 show that the most suitable area is located in Changle. Compared with urban agriculture 1.0, the most suitable area for urban agriculture 2.0 is in Gulou. It is worth noting that Cangshan ranks second in both scenarios and can be used as a potential solution to balance the ecological environment, social demand and investment cost. Determining appropriate land suitability priorities for urban agriculture will facilitate future agricultural investment management and land use planning.

1. Introduction

In recent years, with globalization and the urbanisation process, food security in cities receives widespread attention. Global agriculture faces a food crisis over the next decade due to population growth [1]. In 2022, the global urban population will reach 4.43 billion, accounting for 55.52 % of the global population. A recent FAO report found that 828 million people are suffering from hunger [2]. In addition, climate change and agricultural land shortages will also affect food production [3]. Urban food demand has become one of the challenges that need to be solved urgently [4,5]. The disadvantages of traditional agriculture in terms of low incomes, poor yields and environmental pollution have prompted new ways to improve it [6]. In the process of rapid urbanisation, the inability of traditional agriculture to meet the food needs of urban populations in a more timely and efficient manner has led to the emergence of urban agriculture as a new strategy for agricultural production activities on urban land. Urban agriculture is expected to solve the problem of urban food security by using technology to regulate the climate and sow or harvest smartly, thereby increasing yields and reducing pollution [7]. Urban agriculture meets food needs in a green way and forms a supply chain between cities and agriculture [8]. Furthermore, urban agriculture can supply the urban population nearby and meet the social demand, as an important breakthrough to solving the food crisis [9].

In contrast to traditional agriculture, urban agriculture requires a new set of site suitability criteria. Therefore, it is necessary to analyze the suitability of urban agriculture site selection. First, we review the suitability evaluation criteria for traditional agriculture,

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which mainly considers the influence of ecological factors [10]. Akıncı et al. [11] believed that the site selection criteria for traditional agriculture were mainly based on the ecological environment and considered soil slope, slope aspect, elevation, degree of erosion and precipitation. García et al. [12] selected criteria such as cost, demand and safety to evaluate agricultural site selection. Tercan and Dereli [13] determined that the agricultural land suitability criteria are composed of altitude, air temperature, land use capacity, average daily sunshine hours and average annual precipitation. Cetin [14] studied climate comfort in urban areas and concluded that comfort depends on different elevation and land use. In contrast to traditional agriculture, urban agriculture's technologies such as automatic temperature adjustment can avoid the interference of environmental factors such as climate change to obtain stable and efficient yields [15]. Urban agriculture can better ensure fresh produce, improve supply efficiency, and increase the resilience of cities to climate change [16]. Lucan et al. [17] proposed that the accessibility of urban agriculture, the quality and variety of agricultural products, and the selling price are the keys to its location selection. Zeren Cetin and Sevik [18] conducted a research on the relationship between land use and bio-comfort, which showed that the land use area selection was related to elevation and distance to the coast. Ustaoglu et al. [19] proposed that the factors affecting urban agriculture site selection are mainly ecological environment and transportation, including altitude, slope, precipitation and accessibility. Newell et al. [20] proposed that ecological factors (soil quality, drainage and precipitation) and traffic factors (distance and accessibility) are important criteria for the suitability evaluation of urban agriculture. It is noted that previous studies on land suitability for urban agriculture have focused on ecological factors and transportation accessibility, with less consideration of socio-economic factors. Unlike traditional agriculture, urban agriculture involves technologies such as greenhouse control, lighting systems and automation, and requires investors to have a huge economic budget. O'Sullivan et al. [21] pointed out that urban agriculture needs to invest a lot of infrastructure in the initial stage and reach profitability after a prolonged period of operation. Hosseinpour et al. [22] believe that effective economic budgeting would facilitate sustainable development in urban agriculture. Adenegan et al. [23] emphasized the impact of initial household assets on the profitability of urban agriculture. Moreover, previous studies did not consider the investment needs of urban agriculture under different economic budget constraints. This study will be of interest to investigate the suitability assessment of urban agriculture under different investment scenarios.

How to select an ecologically suitable, easily accessible and potentially investable urban site as a pilot site for urban agriculture is of great importance [24]. Methods used in previous studies to assess the suitability of urban agriculture include the Multiple Criteria Decision Analysis (MCDA), the Analytic Hierarchy Proce (AHP), the Geographic Information System (GIS), and the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), etc [11,19,25–34]. The suitability evaluation of urban agriculture needs to consider a variety of influencing factors, and MCDA is widely used as a mainstream research method. MCDA can be combined with GIS to handle multiple criteria and spatial visualization [11]. Mendas and Delali [25] integrated MCDA into GIS to provide a powerful spatial decision support system for agricultural land suitability. Romanoa et al. [26] integrated GIS and AHP to assess agricultural siting, highlighting a strong correlation between the spatial distribution of suitable areas and multiple standard parameters in AHP. Majumdar [27] applied MCDA and remote sensing image analysis to help urban planners and policymakers to formulate different decisionmaking actions. Cetin et al. [28] used multiple linear regression models to measure and analyze the spatial distribution of bioclimatic comfort and land in the city of Burdur. Cetin [29] then integrated remote sensing (RS) and geographic information systems (GIS) to analyze land cover and land use variations in Bursa, making recommendations for a sustainable urban planning study in the city of Bursa. Cao et al. [30] used the entropy method to obtain index weights when evaluating the suitability of the agricultural production scale, which provided a reference for land resource utilization and policy customization. In the contrast between AHP and the entropy method, the former focuses more on the subjective preferences of decision makers, while the latter focuses on objective facts and focuses on the interrelationships between data. To ensure the scientificity and accuracy of the index weight, many scholars use AHP-Entropy to calculate the comprehensive weight of the evaluation index. Bayat et al. [31] applied the AHP-Entropy-WASPAS technique to evaluate irrigation projects in urban agriculture. The research results show that the combination of subjective and objective methods can improve the scientific accuracy of evaluation indicators. Another complement to the suitability evaluation method is the ranking method. Ranking the evaluation options can help decision makers choose [32]. In 1981, Hwang and Yoon [33] proposed the technique for order preference by similarity to ideal solution (TOPSIS) for the first time to rank alternative decision points. TOPSIS can accurately reflect the gaps between the different options [34]. Ustaoglu et al. [19] studied the suitability of urban agriculture development, using the TOPSIS method to prioritize agricultural development in 8 different regions. In recent years, many studies have begun to use economic methods to examine the state of urban agriculture, rather than being limited to traditional methods such as AHP and GIS. Wang et al. [35] developed a system dynamics model considering economic risks to simulate the market promotion of urban agriculture under various technological innovations. Hosseinpour [22] proposed the cost-benefit value index of urban agriculture based on the net present value method, and combined value engineering (VE), risk management (RM) and other technologies to evaluate the economic benefits of urban agriculture. Caputo et al. [36] proposed a comprehensive method UA Nexus to analyze urban agriculture at the micro level, including urban agricultural activity database, life cycle assessment and material flow analysis, etc., emphasizing the behavioral decision-making of operators. Arene and Mbata [37] analyzed the profitability of urban agriculture using the profit function and emphasized the importance of behavioral characteristics of urban farmers. The above discussion is mainly based on utility theory to assess the risks and losses of urban agriculture, assuming that the decision-maker is fully rational and the goal is to maximize utility. However, utility theory is limited in explaining the uncertainty of risk and cannot explain the irrational behavior of decision-makers. Prospect theory nicely compensates for this limitation. Prospect theory holds that individuals take into account psychological factors such as loss aversion and risk aversion when making decisions. Therefore, this study will employ prospect theory to capture the risk preferences of urban agriculture investors and explore the suitability assessment of urban agriculture under different investment scenarios.

To sum up, traditional agriculture only considers ecological and environmental factors, while urban agriculture is affected by social demand and economic markets. Therefore, we considered applying socioeconomic factors to urban agriculture suitability evaluation. In addition, it is necessary to incorporate heterogeneity into the study, since there are differences in the evaluation criteria of urban agriculture by different investors. Investors in traditional agricultural products pay more attention to investment costs and ecological factors to ensure stable returns. Investors in urban agriculture are more concerned about social demand, for example, healthy and pollution free green agricultural products will be favored by high income groups. However, most studies have primarily focused on land suitability and economic benefits, neglecting the influence of social demands from diverse investors and the potential transformations of urban agriculture under varying economic scenarios. More specifically, this study will tackle the following inquiries: (1) Which factors contribute to land suitability for urban agriculture? (2) Are there variations in the investment demands among different investors? (3) What are the economic advantages of urban agriculture across distinct investment scenarios?

In this study, we combine multidisciplinary approaches such as agriculture and economics to evaluate the suitability of urban agriculture under different investment scenarios based on synthesis methods such as AHP, TOPSIS and prospect theory. Table 1 shows the characteristics that distinguish this study from others. The main contributions of this study are: (1) Unlike previous studies, we incorporate socioeconomic factors into the urban agriculture suitability evaluation, including GDP, population density, land rent, and accessibility; (2) We consider different investment demand scenarios to construct urban agriculture 1.0 and 2.0, respectively, and provide personalized evaluation recommendations for investors with different economic budgets; (3) Prospect theory is used to describe the risk preferences of different investors and to provide personalized investment assessment recommendations for heterogeneous investors.

The rest of the paper is structured as follows: the second section is material and methods, where urban agriculture 1.0 and 2.0 are set up for different investment scenarios, and urban agriculture suitability evaluation metrics and methods are presented. The third section is the results and analysis, which analyzes the land suitability of urban agriculture 1.0 and 2.0 in Fuzhou City as an example. The fourth part is the discussions and conclusions.

2. Materials and methods

2.1. Case study and investment scenarios

2.1.1. Study area and data

Urban agriculture is expected to solve food insecurity by increasing crop yields and reducing the environmental pollution. We choose Fuzhou as the study area (Fig. 1). Fuzhou is located at the estuary of the Minjiang River on the southeastern coast of Fujian, bordering Taiwan in the east, connecting with the most important economic circles in China such as the Yangtze River Delta and the Pearl River Delta in the south and north respectively, and directly connecting to the economic hinterland of inland China in the west. Consistent spatial data on geographic features, land use, etc. can be obtained more completely. The climate of Fuzhou is a typical subtropical monsoon climate, which is warm and humid all year round, with plenty of sunshine, abundant precipitation, long summers and short winters, and a frost free period of up to 326 days. The average annual temperature is 20∼25 °C, the average temperature in January is 6∼10 °C, and the average temperature in July is 33∼37 °C. Fuzhou is one of the first 35 districts in China to develop urban agriculture [38]. Fuzhou has clearly divided the urban economic circle, including core areas such as Gulou, Taijiang, Jin'an, Cangshan, Mawei, Minhou, Lianjiang and Changle, with a total area of 2207 km^2 and a population of about 4.487 million.

The data used in this study include ecological environment and socioeconomic data (Table 2). Ecological environment data mainly includes land use, elevation and precipitation data. Land use data are mainly from the Global Land Cover Data Product Service website of the National Geomatics Center of China. The 30 × 30 m resolution digital elevation model (DEM) dataset is derived from the Geospatial Data Cloud. The precipitation data came from the Resource and Environmental Science and Data Center of the Chinese Academy of Sciences. Socioeconomic data include GDP, population density, land rent and transport accessibility data. The grid data of GDP spatial distribution kilometers network [39], and the raster data of population spatial distribution [40] are from the Center for Resource and Environmental Science and Data of the Chinese Academy of Sciences. The ground rent data comes from Tuliu.com, and the traffic accessibility data comes from the Carbon Cycle Room of the Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences (CAS) [41]. The unified geographic coordinate system for all data is GCS_WGS_1984. The ArcGIS 10.8 platform is used to preprocess the data such as georeferencing, cropping and stacking.

Table 1
Characteristics of some primary references.

References	Suitability evaluation criteria			Research methods			
	Ecological environment	Social demand	Investment cost	AHP	GIS	TOPSIS	Prospect theory
[10]	◎					◎	
[11]	◎			◎			
[13]	◎			◎			
[16]	◎			◎			
[19]	◎			◎	◎	◎	
[20]	◎		◎	◎			
[22]		◎		◎			
[25]	◎			◎	◎		
This study	◎	◎	◎	◎	◎	◎	◎

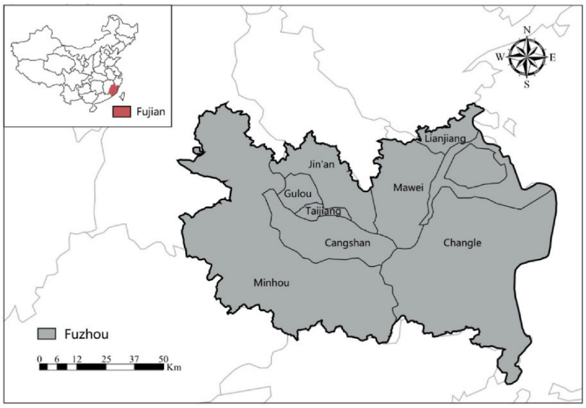

Fig. 1. Geographical location map of the study area.

Table 2
Data source and details.

Category	Main data	Source
Ecological environment	Land elevation	The Global Land Cover Data Product Service website of the National Geomatics Center of China.
	Slope	The Geospatial Data Cloud.
	Precipitation	The Resource and Environmental Science and Data Center of the Chinese Academy of Sciences.
Social demand	Population density	The Center for Resource and Environmental Science and Data of the Chinese Academy of Sciences.
	GDP	The Center for Resource and Environmental Science and Data of the Chinese Academy of Sciences.
Investment cost	Land rent	Tuliu.com.
	Accessibility	The Carbon Cycle Room of the Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences (CAS).

2.1.2. Investment scenarios

Considering different investment needs, we divide urban agriculture 1.0 and 2.0 to analyze different investment scenarios. Urban agriculture 1.0 focuses on traditional soil cultivation. It is greatly affected by extreme weather, which may lead to a significant reduction in food production. Investors pay more attention to the impact of the ecological environment, which requires agricultural products with low prices and short cycles. With the improvement in living standards, consumers tend to choose green organic products, which puts forward higher requirements for agricultural production. Therefore, we refer to the introduction of urban agriculture 2.0 by Ref. [36] The schematic diagram is as follows (Fig. 2).

Compared to urban agriculture 1.0 (see Fig. 2 (a)), urban agriculture 2.0 (see Fig. 2 (b)) has a higher initial investment cost due to the addition of automated equipment, including greenhouse systems and photovoltaic systems. The agricultural products of urban agriculture 2.0 have the advantages of not relying on the external environment, stable output and green premium: (1) The greenhouse system achieves the optimum by adjusting the growth environment of agricultural products, so as to avoid the disturbance of the ecological environment and achieve stable production; (2) The irrigation mode of the soilless hydroponic cycle can effectively avoid the use of chemical fertilizers and pesticides, which provide consumers with organic and green agricultural products, obtain brand premiums and increase profits; (3) The adoption of automation equipment and photovoltaic energy systems can reduce manpower and energy costs.

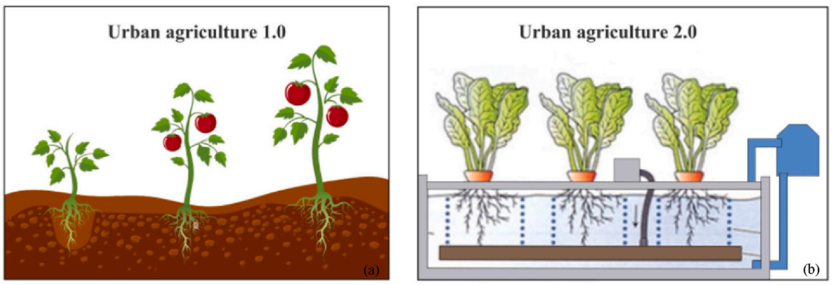

Fig. 2. The schematic diagram of urban agriculture 1.0 (a) and 2.0 (b).

2.2. Land suitability evaluation of urban agriculture

The evaluation of the suitability of urban agriculture mainly lies in the selection of criteria, and we screen the spatial data in order to find suitable evaluation factors. The combination of AHP and TOPSIS provides a powerful decision support system that provides an opportunity to efficiently generate these land suitability maps (Fig. 3).

First, we construct the land suitability evaluation of urban agriculture. The literature suggests that a variety of factors may influence the growth of urban agriculture. Combined with the availability of data in Fuzhou, the following evaluation factors (Table 3) are used to conduct land suitability analysis for urban agriculture: (1) Ecological environment: land elevation, slope, and precipitation; (2) Social demand: population density and GDP; (3) Investment cost: land rent and accessibility.

2.2.1. Ecological environment

In terms of ecological environment, impact criteria include land elevation, slope and precipitation considering the threat of land erosion to urban agriculture. Soil erosion negatively affects urban agricultural productivity by reducing rooting depth, degrading soil structure, and depleting soil nutrients [53]. Land elevation changes affect land suitability for urban agriculture through factors such as soil and climate. The higher the elevation, the more prone to erosion risks, and temperature changes also affect the growth of food crops [42]. Food crop yield is inversely proportional to elevation [13]. Generally speaking, the growth cycle of food crops is delayed by 4–6 days for every 100 m of elevation, crops such as rice, wheat and corn are more suitable for low land elevation areas [43]. Slope affects soil thickness and is one of the main factors determining erosion control, relatively gentle soil nutrients, minerals and, agricultural productivity are more suitable [44]. With increasing slope, soil development is slow and soil depth and fertility decrease [45]. The slope within 30° is suitable for agricultural production [54,46]. Precipitation is a necessary condition that guarantees the growth of crops by the natural annual precipitation, which represents the water resources situation [47]. Water is very important for the production of urban agriculture, especially for arable crops.

2.2.2. Social demand

In terms of social demand, we choose population density and GDP to measure urban agricultural demand. Population density means the density distribution of the population in a district, which determines residents' demand for agricultural products [48,49]. GDP is the total output value of GDP per square kilometer, which represents the consumption level of residents [50]. The level of consumption means that the market potential is huge, and there is more demand for the diversification and organic quality of agricultural products.

2.2.3. Investment cost

We choose land rent and accessibility to represent the investment cost. The land rent is measured by land price or rental cost [51]. Urban centers are generally unsuitable for urban agriculture due to high rents compared to the low rental cost in the suburbs. The accessibility can be understood as the transportation accessibility between the production land and consumers, less accessibility leads to increased transport costs [52].

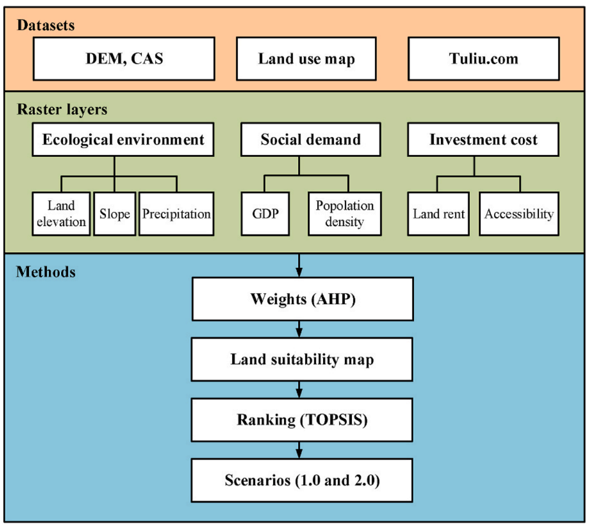

Fig. 3. Land suitability map for urban agriculture.

Table 3
Assessment factors for urban agriculture.

Target layer	Criterion layer	References
Ecological environment	Land elevation	[13], [42,43]
	Slope	[44–46]
	Precipitation	[47]
Social demand	Population density	[48,49]
	GDP	[50]
Investment cost	Land rent	[51]
	Accessibility	[52]

2.3. Methods

2.3.1. AHP

AHP is a decision making technique used to analyze and support decisions with multiple, even competing goals [55]. In AHP, a hierarchical model consisting of goals, criteria, subcriteria and alternatives is used. The weights of the importance of different influencing factors of urban agriculture suitability are determined through pairwise comparison [56].

The first step in AHP is to model the problem as a hierarchy by consulting domain experts. It consists of an overall goal, a group of alternatives for reaching the goal, and a group of factors or criteria that relate the alternatives to the goal. The goal of the decision problem is placed at the top of the hierarchical structure. Other relevant aspects (criteria, subcriteria, attributes, etc.) are placed in the remaining levels [57].

The second step in AHP is to evaluate the hierarchy. Once the hierarchy has been constructed, we analyze it through a series of pairwise comparisons that derive the relative weights for the nodes. Create a matrix of pairwise comparisons that allow for an independent assessment of the contribution of each factor, simplifying the decision making process. The criteria are pairwise compared against the goal for importance. The alternatives are pairwise against each of the criteria for preference. AHP uses a basic 9 point scale measure to express personal preferences or judgments [58], which put a meaningful and objective numerical value on each of the criteria.

The third step in AHP is to check the consistency of the matrix to ensure the significance of the weights. A certain degree of inconsistency may arise when criteria are compared pairwise in AHP. Saaty [55] pointed out that according to the nature of the matrix, the largest eigenvalue $\lambda_{\max}$ is always greater than or equal to the number of rows or columns n, then the consistency ratio CR for measuring pairwise comparison judgment can be expressed as follows

$$\boldsymbol{CR} = \frac{\lambda_{\max} - n}{(n-1) \times RI} \tag{1}$$

in Eq. (1), where $\lambda_{\max}$ is the principal eigenvalue of the pairwise matrix, $\boldsymbol{n}$ is the order of the matrix, and RI is the average value of the consistency criterion obtained according to the order.

The upper limit of the consistency ratio proposed by Saaty is 0.10. If a judgment has a calculated agreement ratio below 0.10, the judgment is considered to show a sufficient degree of agreement to proceed with the evaluation. If the agreement ratio is higher than 0.10, the judgment is considered inconsistent. In this case, AHP may not yield meaningful results unless participants reexamine judgments and revise until the concordance ratio falls below 0.10.

2.3.2. TOPSIS

TOPSIS is a ranking technique by identifying weights for each criterion, normalizes scores for each criterion, and calculates the geometric distance between each alternative and the ideal alternative, which is the best score in each criterion [59]. The chosen alternative should have the shortest geometric distance from the positive ideal solution and the longest geometric distance from the negative ideal solution.

The first stage in TOPSIS is to create an evaluation matrix consisting of m alternatives and n criteria. And we can calculate the weighted normalized decision matrix by AHP. Then we determine the best alternative A^+ and the worst alternative A^-.

$$A^+ = \left\{ \left(\max v_{ij} | i \in I\right), \left(\min v_{ij} | i \in J\right) \right\} = \left\{ v_1^+, ..., v_{1n}^+ \right\} \tag{2}$$

$$A^- = \left\{ \left(\min v_{ij} | i \in I\right), \left(\max v_{ij} | i \in J\right) \right\} = \left\{ v_1^-, ..., v_{1n}^- \right\} \tag{3}$$

in Eq. (2) and Eq. (3), where A^+ is the positive ideal value, and A^- is the negative ideal value. I is associated with the benefit criteria and J with the cost criteria.

The second step in TOPSIS is to calculate the Euclidean distance between the target value and the ideal value

$$S_i^+ = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_{ij}^+\right)^2} \tag{4}$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_{ij}^-\right)^2} \tag{5}$$

in Eq. (4) and Eq. (5), where S_i^+ is the Euclidean distance of the positive ideal point, and S_i^- is the Euclidean distance of the negative ideal point.

The third step in TOPSIS is to determine the proximity C_i^* of each target to the positive ideal

$$C_i^* = \frac{S_i^-}{S_i^+ + S_i^-} \tag{6}$$

in Eq. (6), where $C_i^* \in (0,1)$ is the proximity, $C_i^* = 0$ means that the decision point is close to the negative ideal value, and $C_i^* = 1$ means that the decision point is close to the positive ideal value.

2.3.3. Prospect theory

The expected investment costs of urban agriculture 1.0 and 2.0 are different, considering the energy input and labor costs for lighting, temperature and humidity control, the operating costs of urban agriculture 2.0 are generally high. Energy costs come first, as the controlled environment of urban agriculture 2.0 implies that energy requirements are orders of magnitude higher than urban agriculture 1.0. Labor is the second largest cost after energy and is often considered one of the main economic constraints of urban agriculture. First, the cost of living in urban areas is generally higher than in rural areas. Second, urban agriculture 2.0 often requires more job skills than urban agriculture 1.0, such as the manipulation and maintenance of automated control systems. We use prospect theory to characterize the behavioral decisions investors make under uncertainty (Fig. 4).

According to prospect theory, consumers will set a reference point (such as initial investment cost) based on past experience or market information before making a decision, and make a choice by comparing the difference between the result and the reference point. Consumers tend to show risk aversion for gains above the reference point and risk appetite for losses below the reference point. Then the perceived utility of investors $v_i(p)$ can be expressed as follows

$$v_i(p) = \begin{cases} (\pi_i - p)^\alpha, C_i \geq p \\ -\lambda(\pi_i - p)^\beta, C_i < p \end{cases} \tag{7}$$

in Eq. (7), where π_i is the planned investment cost for different investors, $i = 1$ represents urban agriculture 1.0 and $i = 2$ represents urban agriculture 2.0, α, β and λ are coefficients, which can be determined through questionnaires.

3. Results and analysis

3.1. Land use capability class

First, we determine the range of land suitable for agricultural production. The existing literature adopts the land use classification method to analyze agricultural suitability [60]. We identified different land types from the land use map of Fuzhou, and areas with agroecological environmental value are considered to be extended into agricultural production land [61].

In Fig. 5, the suitable land for urban agriculture is mainly plowland, accounting for 37.61 %. Plowland is mainly located in the east

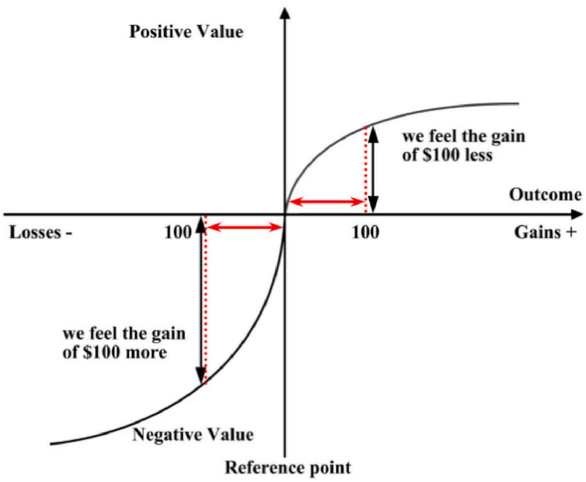

Fig. 4. Perceived utility function of prospect theory.

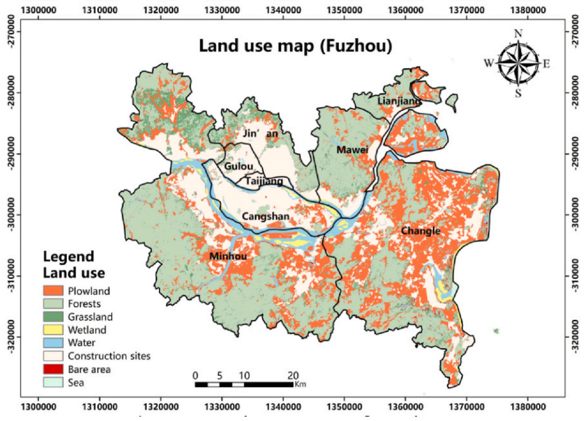

Fig. 5. Land use map of Fuzhou.

and south of Fuzhou, including Changle, Mawei and Minhou. The main urban areas of Fuzhou are Gulou, Taijiang and Cangshan, which are not suitable for urban agriculture due to the dense distribution of residents and public facilities.

3.2. Assessment factor maps

Next, we collect information and data from three aspects: ecological environment, social demand and investment cost. Spatial data processing and raster overlay analysis were performed in ArcGIS 10.8 software, and draw assessment factor maps of urban agriculture.

3.2.1. Ecological environment

The ecological environment includes land elevation, slope and precipitation (Fig. 6). Land elevation is considered to be an important factor in urban agricultural development, high altitude (>400 m) is the key factor limiting the land suitability evaluation of urban agriculture. Based on the DEM, we performed a raster analysis of the elevation in ArcGIS and finally graded its suitability. In

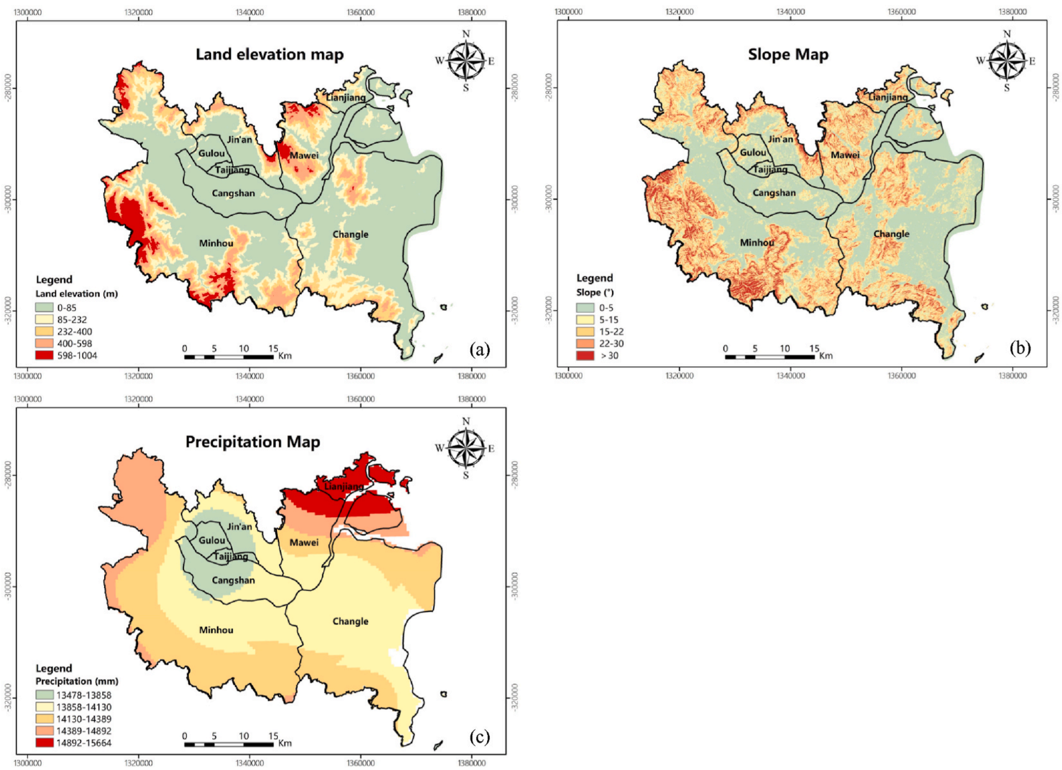

Fig. 6. Assessment factor maps with (a) Land elevation (b) Slope and (c) Precipitation.

Fig. 6(a), it can be seen that the middle of Fuzhou is a plain surrounded by mountains, and the land elevation shows a gradual increase from the inside to the outside. The medium and high suitable areas (0–400) cover most of Fuzhou, accounting for 85.81 %. Among them, the areas distributed in Minhou and Changle have flat terrain and low density of residents, which are suitable for urban agriculture. The low suitable areas (>400) are mainly distributed in Lianjiang, Minhou and Mawei, accounting for 14.19 %. These areas are mainly mountains, and the high altitude causes the temperature difference between day and night, which is not conducive to the growth of crops.

In general, the high soil slope can easily cause erosion risk, thus limiting the land suitability for urban agriculture, so areas with lower slopes are more suitable for urban agriculture. Affected by the subtropical marine monsoon climate, the suitable slope for crop growth in Fuzhou should be less than 30°. In Fig. 6(b), the high suitable areas (<5°) are located in Changle, south of Mawei and north of Minhou, accounting for 62.51 %. These areas are mostly plains with low altitudes and suitable for the growth of crops. The medium suitable areas (5°–22°) are mainly distributed in the suburbs, including Minhou, Jin'an, Changle and Mawei, accounting for 11.23 %. These areas can grow some crops that do not require a high ecological environment. The low suitable areas (>22°) are located in Jin'an, Minhou and Mawei, accounting for 26.26 %. Considering the risk of soil erosion, it is not suitable as an area for urban agriculture.

The amount of precipitation determines the growing conditions and environment of crops. Areas with higher precipitation are more suitable for urban agriculture. The spatial distribution data of precipitation in Fuzhou can be obtained based on the spatial interpolation dataset of annual mean temperature and precipitation. In Fig. 6(c), the high suitability areas (>14892) are located in Mawei and Lianjiang, accounting for 19.71 %. Areas with higher precipitation are more likely to form regional microclimates, making forests richer. The medium suitable areas (13858–14892) are located in Changle, Minhou, Mawei and Cangshan, accounting for 61.94 %. Precipitation in these areas is appropriate, which basically meets the local urban agricultural production. The low suitable areas (13478–13858) are mainly concentrated in Gulou and Taijiang, accounting for 18.35 %. These areas are urban areas, with low mountain and green coverage, and less rainfall due to urban microclimates.

3.2.2. Social demand

Social demand consists of GDP and population density, which are important factors affecting the development of local urban agriculture. In Fig. 7(a), the high suitable areas (1212568–9735124 $/ha) are located in Gulou, Taijiang and Jin'an, accounting for 12.63 %. These areas are the urban center of Fuzhou that high income residents have greater demand for high quality agricultural products. In addition, the medium suitable areas (137970–1212568 $/ha) are located in Cangshan, Changle, Jin'an and Mawei, accounting for 54.13 %. These areas are relatively low in GDP relative to the city center and belong to new construction areas. The low suitable areas (14504–137970 $/ha) are located in Minhou and Lianjiang, accounting for 33.24 %. These regions have lower GDP due to inaccessibility and lower population density.

We obtained the population data of Fuzhou from the grid dataset of China's population spatial distribution provided by CAS. In Fig. 7(b), the medium and high suitable areas (68–274 persons/ha) are located in Cangshan, Taijiang, Gulou and Jin'an, accounting for 68.76 %. The residents in these areas are concentrated with complete infrastructure and large flow, which have a high demand for agricultural products. The low suitable areas (0–68 persons/ha) are located in Minhou, Changle and Mawei, accounting for 31.24 %. These areas are not suitable for urban agriculture due to their scarcely populated.

3.2.3. Investment cost

Investment cost include land rent and accessibility. In general, land rent is an important factor affecting the development of urban agriculture, and low rent areas are more suitable for urban agriculture. We build a spatial analysis in ArcGIS based on land rent, and finally obtain an urban agriculture suitability analysis for land rent. Since there are certain limitations in directly obtaining land prices, we choose the average land price in each district and county to represent land rent. In Fig. 8(a), the high suitable areas (1504–1615 $/ha) are located in Changle, accounting for 32.12 %. Changle is close to the sea and has more salinealkali land, so land rent is cheap. The medium suitable areas (1615–1756 $/ha) are located in Cangshan and Mawei, accounting for 55.78 %. There are parts of plowland

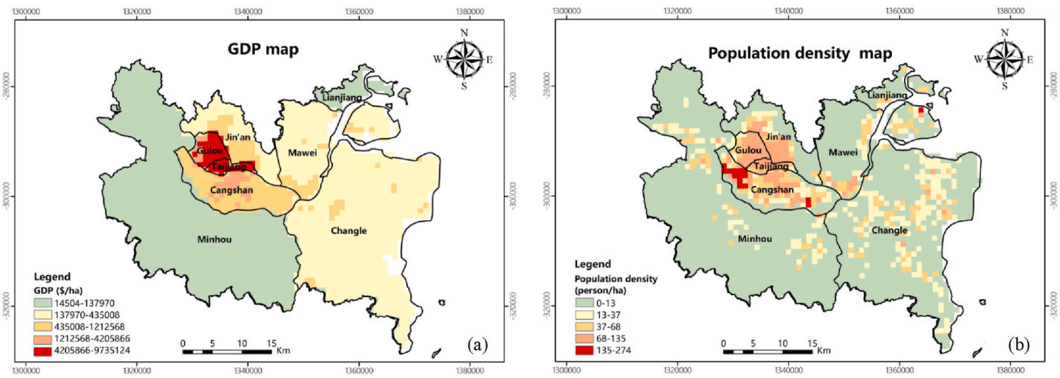

Fig. 7. Assessment factor maps with (a) GDP and (b) Population density.

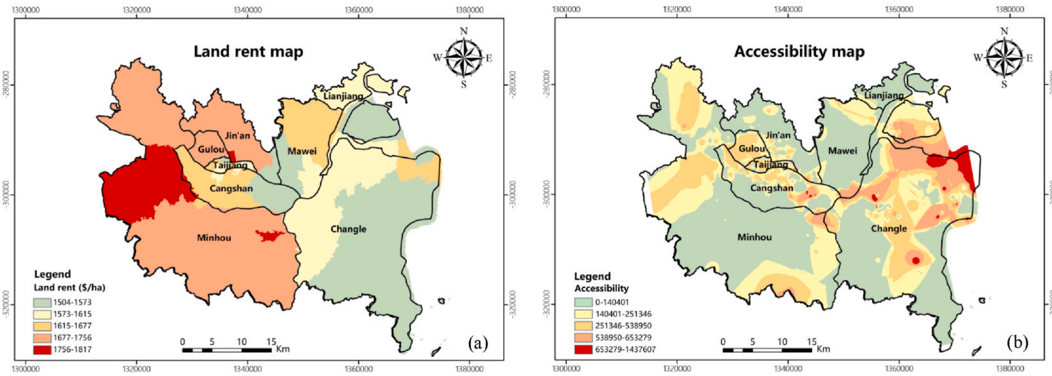

Fig. 8. Assessment factor maps with (a) Land rent and (b) Accessibility.

with soil hardening in Cangshan, so the land rent is relatively low. The low suitable areas (1756–1817 $/ha) are Minhou and Jin'an, accounting for 12.10 %. It is worth noting that Minhou belongs to the key development zone of Fuzhou, so the land rent is higher.

Accessibility affects transportation costs, which are limited to the distance from main and secondary roads. We analyze the Euclidean distance on the traffic network in ArcGIS to obtain the assessment factor maps with accessibility. In Fig. 8(b), the high suitable areas (653279–1437607) are located in Changle, accounting for 13.42 %. The reason is that the international airport is located in Changle, and the surrounding transportation facilities are perfect, so the accessibility is high. The Changle government can increase revenue by transporting fresh agricultural products to the city center through the airport. The medium suitable areas (251346–653279) are located in Cangshan, Gulou and Minhou, accounting for 48.61 %. Because of the high density of living in these areas, the roads are relatively complete and the transportation is convenient. In addition, the low suitable areas (0–251346) are located in Mawei and Lianjiang, accounting for 37.97 %. The low suitable areas are far from the main city, so the transportation cost is higher.

3.3. Results and analysis

3.3.1. Weights

Then, we calculate the weights for land suitability evaluation of urban agriculture, which are determined according to AHP. We selected 30 experts to score the importance of each criterion and then determine the weight. Considering the difference in investment cost such as greenhouses and control lighting, and CO2 concentration, participants give different weights to urban agriculture 1.0 and 2.0. Referring to the average random consistency criterion, the matrix has passed the consistency check.

In the target layer of urban agriculture 1.0, the ecological environment has the highest weight of 0.434, followed by the investment cost, with a weight of 0.365 (see Table 4). It implies that the investment cost is second only to the ecological environment in urban agriculture 1.0. In the ecological environment, the land elevation has the highest impact value with a weight of 0.189, followed by the slope with a weight of 0.151, and precipitation is the lowest with a weight of 0.093. The land elevation and slope determine soil quality more attention. In the social demand, the weight of population density and GDP is 0.091 and 0.111, respectively. GDP mainly reflects people's demand for urban agricultural quality, while the population density is closely related to people's volume of demand for urban agriculture. In the investment cost, the weight of land rent is 0.236 and the weight of accessibility is 0.128. The land rent is weighted twice as much as accessibility, which means that the land rent has a stronger impact on Investment cost.

Compared with urban agriculture 1.0, the social demand of urban agriculture 2.0 is more important, and the weight is 0.548. Besides social demand, the second impact is investment cost, with a weight of 0.349. From the perspective of investors, the demand and supply chain of urban agriculture 2.0 is even more important as it focuses on the high end market. Since the ecological environment of urban agriculture 2.0 is set as a stable situation, its weight is much lower than that of urban agriculture 1.0. In the social demand of urban agriculture 2.0, GDP is the most important with a weight of 0.302, followed by population density with a weight of 0.247. High GDP determines the level of consumption, and consumers have more budget to obtain food. Population growth leads to an

Table 4
Weights distribution of urban agriculture 1.0 and 2.0.

Target layer	Weights		Criterion layer	Weights	
	1.0	2.0		1.0	2.0
Ecological environment	0.434	0.103	Land elevation	0.189	0.063
			Slope	0.151	0.018
			Precipitation	0.093	0.022
Social demand	0.201	0.548	Population density	0.091	0.247
			GDP	0.111	0.302
Investment cost	0.365	0.349	Land rent	0.236	0.226
			Accessibility	0.128	0.123

increase in the social demand for agricultural products. In investment cost, land rent is still the most important factor affecting urban agriculture, followed by accessibility.

3.3.2. Total suitability map

Fig. 9 illustrates the results of urban agriculture suitability in Fuzhou. The grid cells are based on 30 m, with suitability scores ranging from the lowest to the highest. We divided agricultural site suitability into five types: currently not suitable, less suitable, marginally suitable, moderately suitable and highly suitable, represented by blue to red. Unified control variables: accessibility, GDP, population density, land elevation, slope and precipitation. Adjust land rent under the two urban agriculture modes, differentiate the situation according to the weight, and finally get the different location ranges of the two modes.

In Fig. 9(a), the suitable areas for urban agriculture 1.0 are mainly distributed in the southeast of Fuzhou. Changle is the most suitable area, accounting for 37.43 %. It has the advantages of a large land area and low rent. Changle is far from the city center, which increases transportation costs and is not conducive to the storage of perishable agricultural products. Another suitable area is the eastern part of Cangshan, accounting for 4.91 %. Land rent is cheap due to the agglomeration of the ground, and other conditions can also meet the needs of urban agriculture 1.0. Compared with urban agriculture 1.0, the suitable area for urban agriculture 2.0 is mainly distributed in the west of Fuzhou (see Fig. 9(b)), and the most suitable area is the Gulou, accounting for 3.66 %. The investors of urban agriculture 2.0 are more sensitive to social demand, and the high income residents of Gulou have boosted demand for urban agriculture. Minhou is the second suitable area, accounting for 36.21 %. Minhou is close to the city center of Fuzhou, with a suitable climate and available arable land for urban agriculture.

3.3.3. Sub suitability map

In Fig. 10, urban agriculture 1.0 has a wider range of suitable areas. The high suitability areas (46.37 %) of urban agriculture 1.0 are distributed in the central plain, which is suitable for the growth of crops (see Fig. 10(a)). Compared with urban agriculture 1.0, urban agriculture 2.0 (Fig. 10(b)) has fewer high suitability areas (11.50 %), which are located in Gulou, Cangshan, Jin'an, Changle and Minhou. In Fig. 11, there is little difference between urban agriculture 1.0 and 2.0 because their weights are basically the same (see Fig. 11(a) and (b)).

Investors' choice of reference points (planned investment cost) leads to differences in the suitability of investment cost (Fig. 12). Compared with urban agriculture 1.0, investors in urban agriculture 2.0 pay more attention to the cost of distance, which can easily affect the freshness of produce. In urban agriculture 1.0, Changle is the most suitable area with 1504–1567 $/ha land rent, which attracts the attention of land rent sensitive investors (see Fig. 12(a)). The second most suitable area is the Mawei with 1567–1630 $/ha land rent, it can be used as an alternative for investment. In urban agriculture 2.0, the most suitable area is Minhou, which is currently the key development area of Fuzhou (see Fig. 12(b)). Although the land rent in Minhou is not low (1756–1817 $/ha), it is close to the city center and can save traffic Shipping costs, and guarantees fresh produce. Another suitable area is Changle, which is mainly due to the large flow of people at the airport and the export of agricultural products.

3.3.4. TOPSIS results

To provide investors with more accurate decision making options, we use TOPSIS to rank the different regions under the two farming models. First, in ArcGIS 10.8 software, we determined the basic data of seven criteria including rent price, accessibility, GDP, population density, land elevation, slope and precipitation in each district and county, and normalized the data. Secondly, according to the data of each standard, the positive and negative ideal values of all standards are calculated in TOPSIS, and finally they are sorted by the results of pros and cons.

From the analysis results of TOPSIS (Table 5), the ranking results of urban agriculture 1.0 and 2.0 are quite different. In urban agriculture 1.0, the most suitable area is Changle, and the least suitable area is Jin'an. In urban agriculture 2.0, the most suitable area is Gu lou, and the least suitable area is Lianjiang. The main reason for this difference is the trade off between investors' budgets for land rent and transportation accessibility. Investors in urban agriculture 1.0 pay more attention to areas with cheap land rent, in order to save costs and maximize profits. Investors in urban agriculture 2.0 focus on accessibility because it guarantees the freshness of produce, which leads to a green premium. It is worth noting that Cangshan ranks second in both scenarios and can be used as a potential solution to balance the ecological environment, social demand and investment cost.

4. Discussions and conclusions

Urban agriculture is strategically significant to mitigate the adverse effects of urban food shortages. In this work, we evaluate the suitability of land for urban agriculture for different investment scenarios based on an integrated approach of AHP, TOPSIS and prospect theory. Specifically, we consider different investment demand scenarios and construct urban agriculture 1.0 and 2.0, respectively. Among them, the risk preferences of different investors are depicted by Prospect Theory, which provides personalized assessment recommendations for investors with different economic budgets. In response to the original question posed, we have come to the following conclusions:

(1) We constructed suitability evaluation indicators for urban agriculture, including ecological environment (land elevation, slope, and precipitation), social needs (population density, GDP), and investment costs (land rent, accessibility).

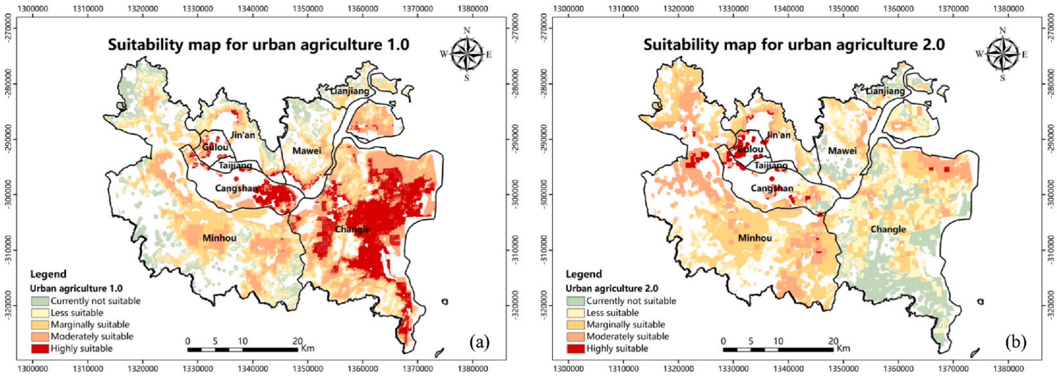

Fig. 9. A comparative analysis of the suitability of (a) Urban agriculture 1.0 and (b) Urban agriculture 2.0.

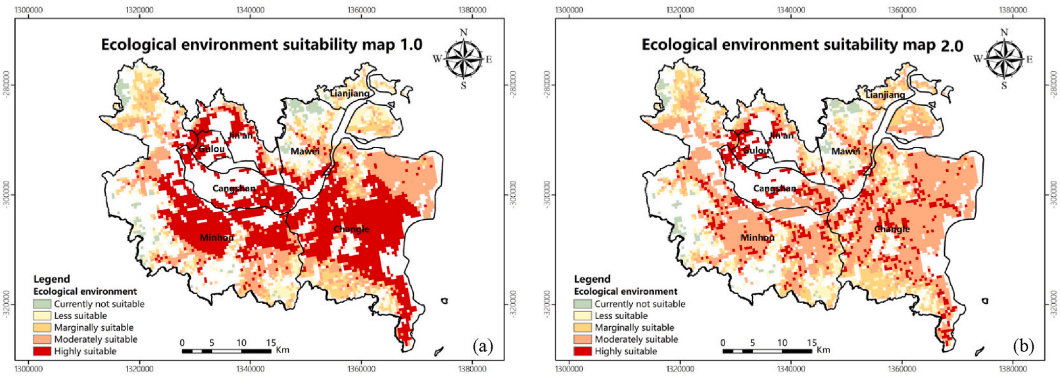

Fig. 10. Ecological environment suitability map for urban agriculture 1.0 and 2.0.

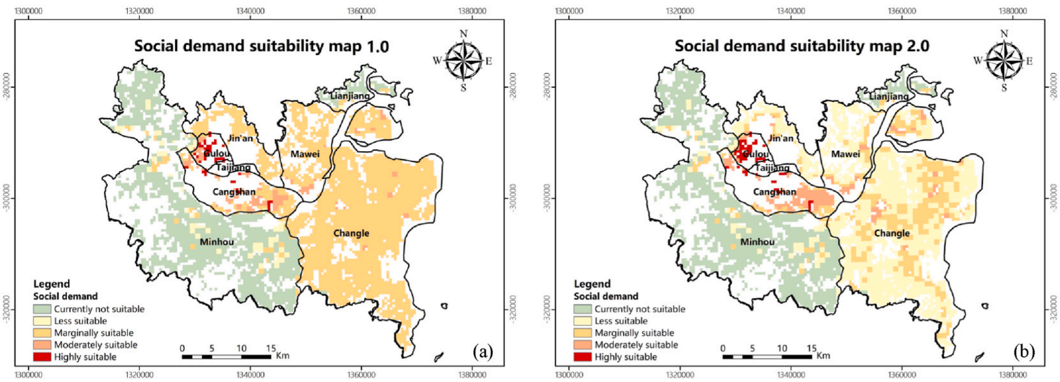

Fig. 11. Social demand suitability map for urban agriculture 1.0 and 2.0.

(2) The results of the scenario analysis show that the suitability of different investment scenarios varies, with the most suitable area for urban agriculture 1.0 being Changle district and the most suitable area for urban agriculture 2.0 being Gulou district. The main reason for this discrepancy is the trade-off between investor subsidies for land rent and transport accessibility.
(3) The focus of different investment scenarios varies, with urban agriculture 1.0 investors focusing on low-rent areas to increase profits and reduce expenses. Investors in Urban Agriculture 2.0 prioritize transportation accessibility to ensure fresh produce and thus increase the green premium.

Due to the limited data collected, the exploration of investor heterogeneity in this study was limited to different investment requirements (urban agriculture 1.0 and 2.0). There are limitations in considering investor requirements, such as age, capital, and individual preferences for different fruits or vegetables, which can be further investigated in future studies. Our future study directions

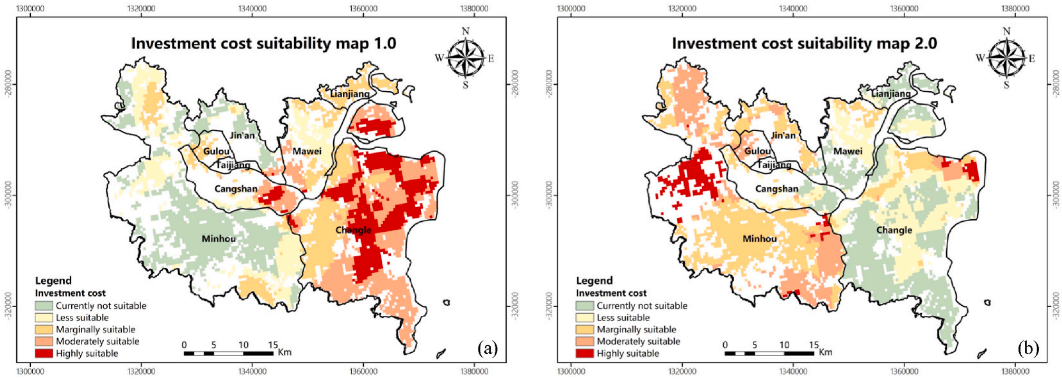

Fig. 12. Investment cost suitability map for urban agriculture 1.0 and 2.0.

Table 5
The score and ranking by TOPSIS method.

Districts	Urban agriculture 1.0		Urban agriculture 2.0	
	Value	Rank	Value	Rank
Gulou	0.451	5	0.829	1
Cangshan	0.708	2	0.635	2
Minhou	0.319	7	0.557	3
Jin'an	0.313	8	0.533	4
Taijiang	0.472	4	0.524	5
Mawei	0.564	3	0.201	6
Changle	0.717	1	0.198	7
Lianjiang	0.388	6	0.139	8

can be divided into two parts. The first objective is to examine the potential returns and benefits of urban agriculture, considering various crop cultivation scenarios. The second goal is to examine how urban agriculture systems operate under diverse conditions and their potential in supplying fresh produce while promoting eco-friendliness for a premium price.

Data availability statement

Data will be made available on request.

CRediT authorship contribution statement

Li Jiaxin: Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization, Writing - original draft, Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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