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A GIS- and Fuzzy Set-Based Online Land Price Evaluation Approach Supported by Intelligence-Aided Decision-Making

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Abstract: In recent years, with the reforms to the land use system and the development of urbanization in China, land price evaluation has tended towards marketization. Prices are determined by the government, the land transaction market and the public. It is necessary to propose higher standards to be used in the evaluation process. This paper presents an online land price evaluation approach for convenience in evaluation. In a network environment, taking advantage of the data services provided by various departments, we propose two models to assist in decision-making: (1) a geographic information system (GIS)- and fuzzy set-based location factor quantification model, which adopts dynamic data, rules and quantification measures (based on the road network) to dynamically quantify location factors, thus transforming fuzzy sets into appropriate values; and (2) a neartude-based transaction sample push model, which quantifies the similarity between a given land and other samples, thus providing a basis for decision-making by an appraiser. This approach is applied in Shenzhen to evaluate its ability to simplify the work of appraisers and make their decisions more intuitive and objective in a real case.

Keywords: GIS; fuzzy set; online; road network; neartude; decision-making

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1. Introduction

Land price evaluation is a process in which the price of land at a certain time is comprehensively evaluated. It is useful for informing land transactions, the investment decisions of enterprises and measures for improving and managing the land market. Appraisers are constantly seeking out new principles, theories and methods of price evaluation so that they can evaluate land prices according to the economic and natural attributes of the land based on a complete understanding of the available land market transaction data. They must consider the impacts of social and economic development, land use, land expected return and land use policies on revenue in accordance with land grades, property quality and average earnings in real economic activities.

A study conducted by Du and Peiser has indicated that the extent of land hoarding by local governments in China is positively and significantly correlated with the granted land prices [1]. Land reforms have been reviewed based on two aspects: changes to land property rights and changes to the system of land rents and land prices. Land prices have skyrocketed in many Chinese markets over the past ten years [2]. The government has acquired a large revenue stream through land transactions because land has become a secure and profitable asset after the land policy reforms. In the land price system, standard land prices are updated slowly and, thus, are always divorced from the real land market; therefore, it is difficult to gain an intuitive understanding of land prices on the land market. The characteristics of the theory regarding land prices and the technology available for land price evaluation lead to the result that prices are not unique. That is, the mechanisms that are used to evaluate land prices are always subject to dispute and criticism. At present, land prices are always evaluated through manual labor, the results of which lag considerably behind the demand for land development, resulting in high costs and low efficiency. In land price evaluations, many aspects, including the selected methods, weights, samples and parameters, can affect the results, such that different choices might lead to different results. Appraisers also differ in terms of accumulated knowledge, experience and subjective cognition. Even if they use common regulations and standards, their choices of methods and parameters are often different. Most cities in China are developing as 'digital cities', which has led to the accumulation of a large amount of basic data, including spatial data and property data, that could be used to assist in the evaluation of land prices. Many countries use information systems to gather and manage information concerning the price of real estate [3,4]. Using this approach, the government could convert land price evaluation from a complicated paper-based process into a simple digital one.

The strongest determinant of land price is usually location. Scholars have found that the most influential factors are the distance to the nearest highway, the distance to the nearest arterial road and the distance to public facilities [5]. Brasington and Hite were the first to estimate the relationship between housing prices (which are related to land prices) and environmental disamenities using spatial statistics, confirming that nearby point sources of pollutants depress housing prices [6]. Thus, location information cannot be neglected in the process of land price evaluation. Appraisers evaluate land prices in combination with information about various characteristics of land, such as their prices and locations, as gleaned from land transactions. In recent decades, geographic information systems (GIS) have gradually become a powerful tool for the management and analysis of data. Scholars have used GIS and landscape metrics to determine hedonic pricing models (HPM) variables. Information systems integrated with GIS are also widely used [7]. A GIS-based decision support system has been presented that can both estimate objective hotel room rates using essential hotel and locational characteristics and predict temporal room rate prices [8]. Some researchers have used GIS methods to solve site-selection problems for real estate projects [9]. A novel, GIS web-based approach that combines land price analysis models and web GIS technologies has been presented [10]. In order to place qualitative land features into numerical form, Papadimitriou and Mairota designed a quantification of qualitative physical-and-human-geographic processes for land management purposes [11]. Artificial intelligence has been employed to render qualitative terms into a form that can be used for calculations by Papadimitriou [12], and algebraic methods have been employed for the prioritization of land units for land management based on qualitative criteria [13]. Zeng and Zhou have presented a prototype real estate GIS by integrating fuzzy set theory and a rule-based system [14].

Scholars are paying increasing attention to analyses and reports of land prices, but rarely explore the evaluation approaches to provide a better working environment and standard to appraisers. Given the high-quality and efficient GIS services, the government could take advantage of these services to improve its management of land price information. Because of the rapid development of cities, the location characteristics of land are always changing, and the government must update land prices quickly and accurately, which poses a significant challenge to appraisers. To reduce controversy regarding land pricing, a good environment for land price evaluation must be created.

To take advantage of the analysis and technology provided by GIS methods, this paper presents an online land price evaluation approach that can enable the full utilization and sharing of basic land data, assist with decision-making and make the entire evaluation process more transparent.

2. Online Land Price Evaluation Approach

Rapid urbanization has increased the demand for data analysis and intelligent decision support. The evaluated price has a direct impact on the land market. It can be used to monitor the dynamics of urban land prices. Change and construction plans occur throughout cities and may influence land prices. From passively receiving data to actively obtaining it, the government collects large amounts of data through information platforms. These data are added to, modified and updated in the database. Appraisers have often complained about an absence of information. Now, they have access to it, but it cannot be used in the traditional approach to evaluation because the data and the evaluation process are relatively independent. Appraisers often use data that have been collected in the past. However, traffic and planning data, land use data, land transaction data and other basic spatial data often change as a city grows, and they are so difficult to obtain, this makes the data outdated for the land evaluation. The traditional approach is no longer well suited to current land price evaluation tasks. First, most of the evaluation parameters and standards used in the process are pre-defined, and the time delay might reduce the accuracy and timeliness of the evaluation results. Second, the workflow is complex. Preparing the data for evaluation is a laborious task. The data may be outdated, and there is no integrated flow that takes advantage of all types of data to evaluate land prices. In addition, the task is tedious and requires appraisers to parse many numbers and words. Third, there are many subjective factors involved in the selection of parameters and samples that can influence the resulting prices.

In the traditional approach, there are many details involved in preparing the data for evaluation, which can be summarized as follows: (1) the appraisers obtain the necessary information for the evaluation land, such as the land code, address and area, from the request file; (2) the appraisers find the general location from the request document and go to the scene to investigate the surroundings and other characteristics of the land; (3) the appraisers choose a suitable evaluation method; (4) the appraisers collect the data needed for the method selected; (5) for the residual method, the appraisers must collect samples based on their subjective experience; (6) the appraisers import the data into Excel and calculate the corresponding price; (7) the appraisers attend a meeting to discuss the results with experts; (8) the appraisers revise the calculated method or parameters in accordance with the comments and suggestions received; (9) the appraisers submit the result. Considering the complexity of this process, we propose a new approach to overcome the problems encountered in the traditional approach.

2.1. Data Sources

Three types of information could be used to improve the results of land price evaluations: evaluation task information, supplementary information and influencing factor information. Evaluation task information includes historical transaction data, benchmark land prices and the parameters used in the process. Supplementary information includes industrial standards, and information about influencing factors includes the base spatial data, land structure data and land location data.

Most of these data have been stored in digital form by government organizations. These organizations are busy with their own daily work, making it difficult for appraisers to schedule meetings with them. Moreover, the methods of data management differ among organizations. To save time and labor, the data collected by local land administrations could be used to build geographic and relational databases using a GIS-based spatial database engine, as shown in Figure 1. Other organizations would need only to publish their data addresses. Their duties would change to manage their data. To fully utilize the opportunities provided by "Big Data", it is imperative that the evaluation of land prices change in this way from an offline to an online process.
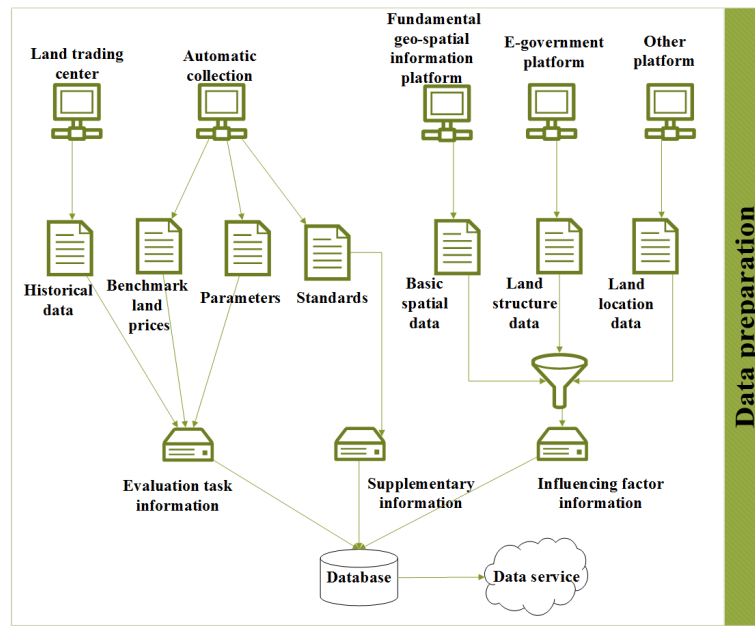
Figure 1. Data preparation procedure.

2.2. Task Flow

At present, the land price evaluation period is complex, long and requires several appraisers to discuss their individual evaluation results. The proposed online land price evaluation approach bridges the gap between data and tasks. It encompasses two workspaces, as shown in Figure 2: the requester's workspace and the appraiser's workspace, which are analogous to a buyer and a seller, respectively.
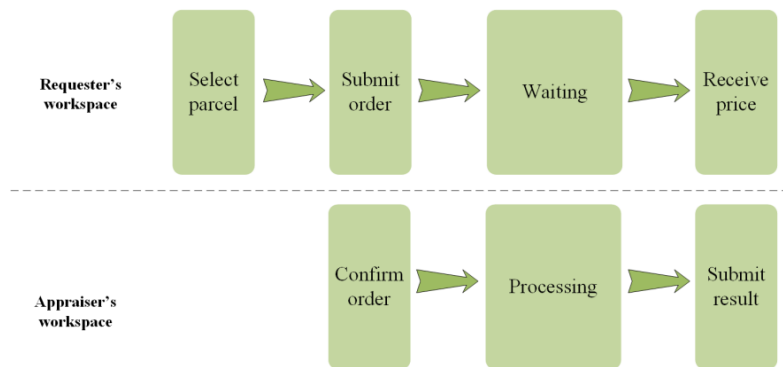

Figure 2. Task flow.

As in the case of a buyer who is shopping on the Internet, an order is created when the requester submits the land to be evaluated and its basic information to the system. The requester then waits for the result. The appraiser receives the order, evaluates the land price and submits the result, playing a role similar to that of a seller. The new approach presented in this paper relies on a process in which every node can be adjusted and supervised by the government.

Data sources such as transaction samples, homogeneous regions, authority files and influencing factors are managed in a database and are used by the appraisers via a web service. An appraiser handles an order by confirming the evaluation task (Step 1), inputting the basic information (Step 2), investigating the land (Step 3), selecting the desired evaluation method (Step 4), selecting the samples (Step 5), revising the parameters (Step 6) and, finally, evaluating the land price. As in the e-commerce website, the requester can trace the current status of his or her order. In addition, before submitting the

result, the appraiser can return to previous steps. The order is complete when an evaluation report is generated for the requester.

2.3. Intelligence-Aided Decision-Making Models

According to the "Regulations for valuation on urban land (GB/T18508-2014)" in China, the main technical methods selected in land price evaluation are the market comparison, income capitalization, residual and coefficient correction of published land prices.

To reduce appraisers' labor and the burden in collecting related data, their professional skills and experience should be fully utilized so that they have sufficient energy to evaluate land prices. Most decision-making should be performed by computers. After the appraisers have confirmed an evaluation task, most basic information is input from the requester's order and the data service. The appraisers' efforts should be concentrated almost entirely on every part of the process from method selection to result generation. During the process of evaluation, certain principles must be observed. The substitution principle, as the most important one, states that the appraiser must consider the transacted price of nearby land which has the same land use. Location factors also appear to have an impact on prices. When the number and frequency of evaluation orders increase, the evaluation approach requires the support of intelligence-aided decision-making. The next section introduces the two models used in the proposed evaluation approach.

2.3.1. GIS- and Fuzzy Set-Based Location Factor Quantification Model

As mentioned above, the spatial distribution of public resources has an effect on land prices, and this effect can be quantified. Researchers utilize the HPM to quantify the effects of public resources on property values [15,16]. Location factors are distinct from structural factors. The former continuously change as urbanization progresses, but the latter has strong stability, and its quantification result can be used for a long time. Regarding the former, this paper uses a quantification model that quantifies the effects of location factors under dynamic conditions. Scholars are in agreement that the same factor can have different effects on land with different land uses. For example, for land that is used for residences, longer distances to industry and better environmental conditions lead to higher land prices. By contrast, for land that is used for industry, a long distance to industry can increase the transaction cost and, thus, reduce the land price.

Figure 3 shows four land use types and their quantitative factor classes. When appraisers wish to know the quantitative factor value for a location, they should estimate the marginal contributions of these factors listed. Scholars have attempted to determine weights that yield a price closest to the actual prices of transactions using methods such as ordinary least-squares regression, HPM and geographically-weighted regression [5,17]. The purpose is to find the most suitable coefficients for evaluating land prices. According to the "Regulations for valuation on urban land (GB/T18508-2014)", the coefficients used to evaluate land prices are valid only for a certain period of time. The weights of the factors could be constants in the model that concentrate on solving for the dynamic changes in the data and their degrees of influence. To assist appraisers in quantifying location factors, this paper presents the following location factor quantification model.

$$S = \sum_{i=1}^{n} (w_i \times \sum_{j=1}^{m} w_j' S_j') = \sum_{k=1}^{m \times n} w_k'' S_k'' \tag{1}$$

The quantitative location factor value S is calculated as the sum of the values for n factor classes, each of which is first multiplied by the relevant weight w_i. Similarly, the quantitative value for each factor class can be obtained as the sum of m factors, where m is the number of factors in each class; for example, the value for Factor Class 1 is the sum of the m quantitative factor values $S_1', S_2', \ldots S_j'$ multiplied by the corresponding weights $w_1', w_2', \ldots w_j'$. The weights are generally confirmed through an expert scoring method [18,19], an analytic hierarchy process [20], the Delphi method or some other method [21].
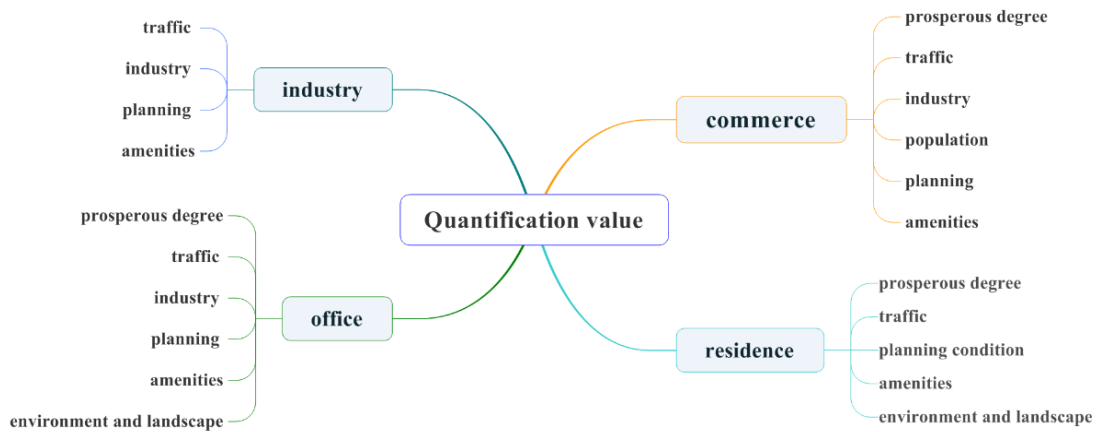
Figure 3. Quantification system.

A diagram of the quantification process is shown in Figure 4. This model is designed to help appraisers to easily obtain a final quantitative value while considering the dynamic changes in quantitative factors, quantitative measures and quantitative rules. The three components are independent, and the quantitative factors are obtained from published layer services. Quantitative measures are provided by several GIS-based analysis tools, including overlay analysis [22], buffer analysis [23] and network analysis [24]. The spatial relationship between lands and their corresponding factors can be understood from such a tool, and this model assigns a score to each factor based on these quantitative measures. The rules of the model are imprecise, and fuzzy sets are used to address this uncertainty. Fuzzy set theory was first proposed by Zadeh to describe the phenomenon of fuzziness [25]. Scholars such as Bellman and Zadeh performed pioneering work by applying fuzzy set theory to solve vague problems in decision-making [26–28]. Based on the concept of sets, fuzzy theory has been developed into a mathematical tool that can be applied to land evaluation. Ponsard conducted a survey of three fuzzy mathematical models concerning economic choice, economic calculation and general economic equilibrium [29]. Burrough used fuzzy mathematical methods for soil surveys and land evaluation [30]. Salski and Bartels used a fuzzy approach to address heterogeneous and imprecise data in land evaluations [31]. As stated by Zimmermann, applications of this theory can be found in many areas, and with the development of computational intelligence, it has emerged as an important means of solving real problems [32]. Once the land use type has been confirmed, this model can consider the relative location factors to the evaluated land.
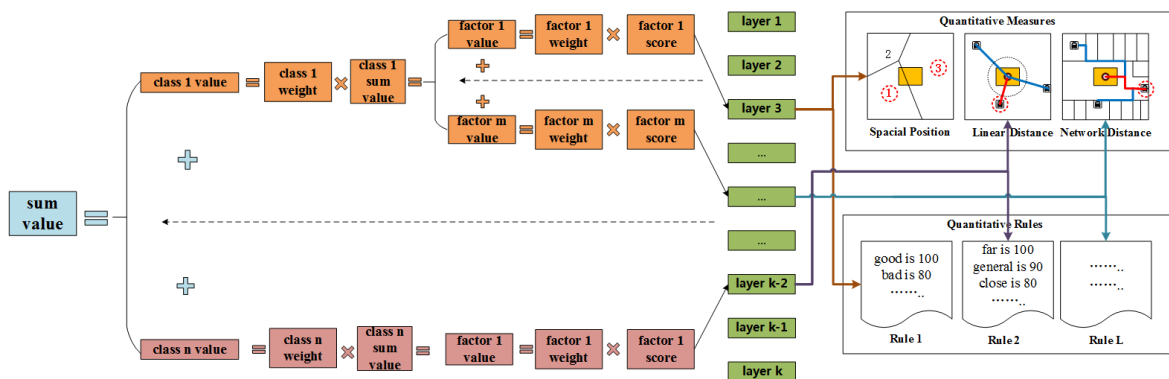

Figure 4. Quantification process.

First, a membership function is established using fuzzy rules. Most fuzzy rules should be generated by the appraisers based on expert experience. Currently, such a rule may take one of two forms:

1. If the shortest distance between factor B and land A is less than x_1 m, then the value is Y_1. If this distance lies in the range of x_1 m to x_2 m, then the value is $f(x)$ or Y_2, where $f(x)$ is a function that reflects the relationship between the quantitative value and the shortest distance. If this distance is greater than x_2 m, then the value is Y_3. For factors that are considered to be worse as their values increase, this model uses the trapezoidal distribution, as follows:

$$F(x) = \begin{cases} Y_1, & (x \leqslant x_1) \\ f(x) \quad or \quad Y_2, & (x_1 < x < x_2) \\ Y_3, & (x \geqslant x_2) \end{cases} \tag{2}$$

$$Function[F(x) = Y_1] > Function[F(x) = f(x) \quad or \quad Y_2] > Function[F(x) = Y_1] \tag{3}$$

2. On the condition that the location of land A is within the district of factor B, if the grade is x_1, then the value is Y_1. If the grade is x_2, then the value is Y_2. If the grade is x_{n-1}, then the value is Y_{n-1}. If the location of land A is outside the district of factor B, then the value is Y_n. This model uses the following distribution function:

$$F(A,x) = \begin{cases} Y_1, (A \cap B = 1 \& x = x_1) \\ Y_2, (A \cap B = 1 \& x = x_2) \\ \dots \\ Y_{n-1}, (A \cap B = 1 \& x = x_{n-1}) \\ Y_n, (A \cap B = 0) \end{cases} \tag{4}$$

$$Function[F(A,x) = Y_1] > Function[F(A,x) = Y_2] > \dots > Function[F(A,x) = Y_n] \tag{5}$$

The fuzzy rules are described by membership functions. When calculating the score of one factor, it is necessary to set a priority rule that states that if the factor has satisfied a previous function, then there is no need to consider any other function, as established by Equations (3) and (5). This model can quantify every factor according to the relevant measures. Different factors influence land prices in different ways. Generally, three types of measures are used to analyze the relationships between an evaluated land and its associated factors:

In Figure 5, Polygon A represents the land to be evaluated. B1, B2 and B3 represent the influencing factors, such as trade areas with associated grades, metro stations and hospitals. In this model, location factors are quantified in three ways on present.
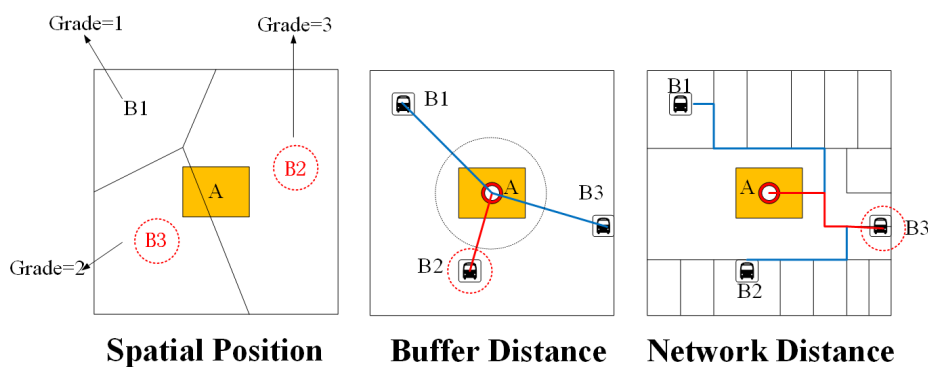

Figure 5. GIS-based Quantitative measures.

1. Related to spatial position:

In this case, B1, B2 and B3 are distinguished by grade and influence Land A by their intersection with its area. According to an overlay-based GIS analysis, Land A intersects with B2 and B3. The second membership function form, described by Equation (4) and the priority rule (5), is applied, such that if grade = 2 is prior to grade = 3, then $F(A,x) = F(A,2)$.

2. Related to buffer distance:

When factors B1, B2, and B3 influence Land A by means of buffer distances, the model finds the closest factor (B2) and calculates the corresponding distance *L*. The first membership function form, described by Equation (2) and the priority rule (3), is applied, where $F(x) = F(L)$.

3. Related to network distance:

As in Case 2, the model finds the closest factor (B3), calculates the distance *L* and uses Equation (2) and the priority rule (3) to quantify the factor. In this case, however, the model finds the closest path through the road network, which is intended to represent a person's daily path through the city.

2.3.2. Neartude-Based Transaction Sample Push Model

The selection of similar samples is the most vital step in land price evaluations. The appropriateness of the selected samples directly affects the final result of the market comparison approach. The influence of the appraiser's preferences always makes it difficult to identify the best samples. To establish the land price system, the government divides cities into several homogeneous regions and evaluates their prices, which are then used to grade the land. The characteristics, location-related conditions and land prices are similar for lands in the same homogeneous region. The scope for the selection of similar samples from a city can therefore be narrowed to the same region or a similar region. Moreover, the appraiser must find the most appropriate samples from the similar ones. The proposed model takes advantage of fuzzy set theory to quantitatively describe the similarities between the target land and selected samples.

Zhang and colleagues extended the construction of the spatial error model (SEM) from a single variable to multiple variables using fuzzy mathematics; this extension increases the applicability of our technique and provides technical support for the ongoing property tax reforms in the Chinese real estate market [33]. To assist in decision-making regarding a reference sample, the proposed model uses fuzzy mathematics to establish fuzzy sets of samples and automatically pushes the most similar samples based on neartude, which is an important index introduced by Wang that describes the degree of similarity between two fuzzy sets [34]. Neartude has been widely used in many fields, and many variants have been developed. Different neartudes offer different levels of efficiency when used to solve practical problems.

Theorem 1. *Suppose that there are two fuzzy sets A and B that contain corresponding factors. There exists a rational number ρ(A, B) that satisfies the following:*

(1) $0 \leqslant \rho(A, B) \leqslant 1$;

(2) $\rho(A, B) = \rho(B, A), \rho(A, A) = 1$;

(3) $if\ A \subseteq B \subseteq C,\ then\ \rho(A, B) \geqslant \rho(A, C)\ and\ \rho(B, C) \geqslant \rho(A, C)$,

then the value of ρ(A, B) is the neartude of A and B.

Based on previous works [27,28], the proposed model uses the maximum–minimum closeness method, which is a common and practical computational method. The degree of similarity can be calculated as follows:

$$\mu(A, B) = \sum_{i=1}^{n} \min(A(x_i), B(x_i)) \bigg/ \sum_{i=1}^{n} \max(A(x_i), B(x_i)) \tag{6}$$

In Equation (6), $\mu(A, B)$ is the neartude measure for fuzzy sets *A* and *B*, *n* is the number of location factors and $A(x_i)$ is the quantitative value of the *i*-th factor and is treated as a weight.

Using fuzzy sets and neartude measures, the model can classify samples according to the degrees of similarity between evaluated land and other samples to assist appraisers in decision-making.

3. Study Area and Evaluation

Compared to the conventional approach, the proposed online land price evaluation approach assigns most of the necessary work to computers. From the preparation of the data to the outputting of the result, a land price evaluation system based on this approach can solve a number of practical problems. In this paper, we consider a selected land in Shenzhen and evaluate its price using the proposed online land price evaluation method. Its area is 29,000 m^2, and the area used for residence is 12,000 m^2.

The standardization and automation of land price evaluation are soon to arrive, and this could facilitate the healthy development of the land market. Shenzhen was selected as the example city for this study because Shenzhen was the first Special Economic Zone to develop into an international city since the 1980s. Its land market is often studied [35,36]. A land price evaluation system was applied by the government early in the development of Shenzhen. However, the evaluation approach is out of date and cannot adapt to the growing and changing data. The city is located in Guangdong Province of southern China and has a total urban area of 1996.85 km^2, a population of 10.78 million and a gross domestic product (GDP) that had increased to 246.23 billion dollars by 2014. The demand for land is strong, but the inefficiency of the old approach leads to inconsistent management and unreliable results of land price evaluations. Therefore, a system that used the proposed GIS-based online land price evaluation approach supported by intelligence-aided decision-making should have practical significance and demonstrable effects.

3.1. Data Preparation

For this paper, a real sample was selected that has previously been evaluated by appraisers, and the main flow of the evaluation process was designed to satisfy the standards specified by the "Regulations for valuation on urban land (GB/T18508-2014)" in China.

The land selected for this application of our approach, which is shown in Figure 6, is a real case that has been evaluated by appraisers using the old system, and the process and results of this evaluation have been accepted. The primary data include lands, homogeneous regions, road networks, location factors and authority files. The selected land is residential land located on Minzhi Street in Longhua District of Shenzhen Province.

Homogeneous regions were first generated using the basic grid that divides the city. The regions corresponding to each land use type were divided according to the relevant influencing factors and measures. To create homogeneous regions according to the quantitative values associated with the influencing factors, the basic grid was divided following the standards for land classification gradation in China. The grades are defined based on the quantitative factor values. A higher land value corresponds to a larger number. The homogeneous regions reflect the spatial distribution of the land price grades in different regions and reveal the differences and inherent trends in the distribution of land prices.

The road network is important in the approach described in this paper. We use the network distance instead of the straight-line distance to quantify the spatial relationships between the land and its corresponding location factors for certain factors, for which quantification based on the network distance is more accurate than quantification based on the straight-line distance. As shown in Figure 7, AB and AC are the straight-line distances from A to B and C, respectively, whereas ADEB and AFC are the network distances from A to B and C, respectively. The different measures yield different results: the straight-line distance from A to B is the same as that from A to C, but we can conclude that Land A is closer to Metro B than to Metro C in terms of the network distance. The network distance is more representative of the behavior patterns of residents.

The authority files include several standards, such as the correction coefficient table, tax rate table and quantification table (factors and weights). The data contained in these files have good stability, and they can be obtained online.
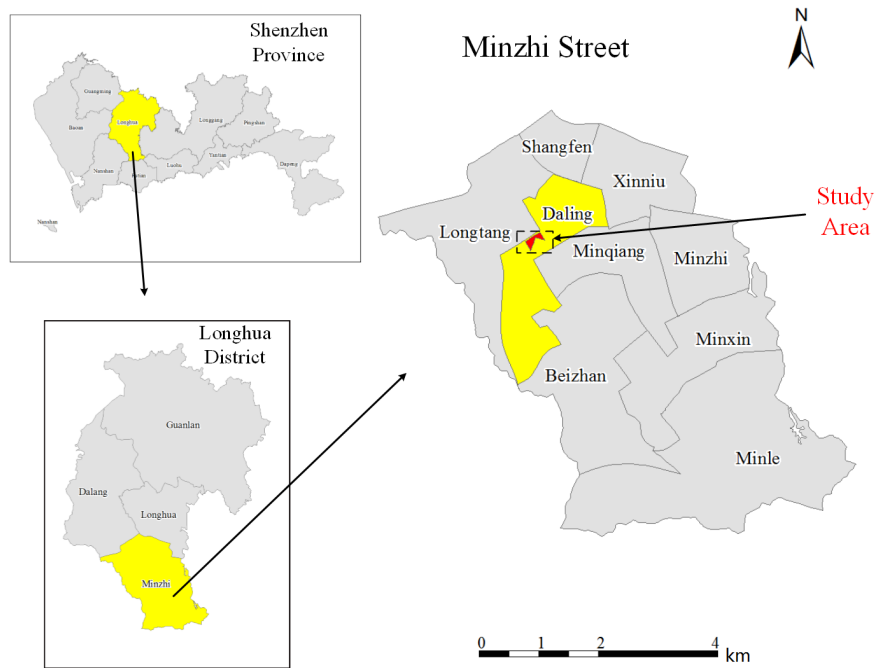
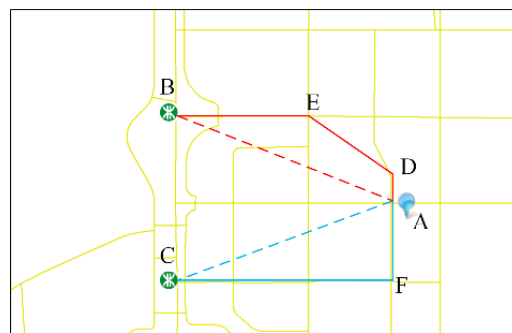**Figure 6.** Location of the land considered in the case study.

Figure 7. Road network in Shenzhen.

3.2. Implementation of the System Using the Residual Method

The entire evaluation process can be completed in a web browser. The requester logs into the workspace and submits an order, which contains the basic information of the land written in a standard format. The appraisers confirm the order in the browser and begin work. As shown in Figure 8, the case selected is residential use. After the information has been input, the system collects the basic information from the web service as published from the relevant data sources, the appraiser confirms the information and then selects the residual method for the evaluation.

In the residual method, the real estate price must be calculated while considering the development of the land, the cost of development and related fees, profits and taxes, among other factors. The land price is:

$$V = A - (B + C) \tag{7}$$

In this equation, V is the land price per square meter, A is the real estate price per square meter after development, B is the development cost per square meter and C is the developer profit per square meter. In the old system, the calculation process involves collecting the necessary information from other sources, completing the work in other professional software and inputting only the result. However, the calculation process must be standardized; excessive influence from subjective opinions may affect the final result. Based on the online land price evaluation approach introduced in this paper,

the new system takes advantage of the spatial analysis tools provided by GIS methods and fuzzy mathematics to assist appraisers in making decisions.
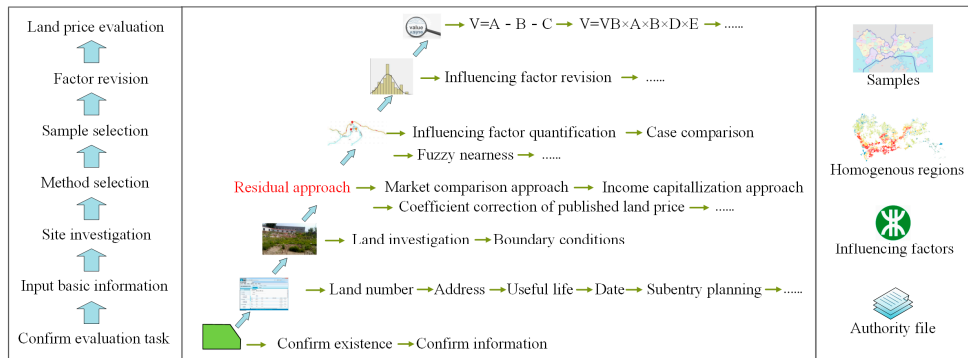

Figure 8. Common evaluation process using the residual method.

The advantages of using this approach lie in the calculation of the real estate price. The market comparison method is commonly used for this calculation, and the appraiser must use similar transaction samples to determine real estate prices. To identify similar samples, the appraiser must select the most appropriate measures to quantify the factors that influence the price as a basis for choosing the most similar samples.

We use the residual method to evaluate the considered case. The evaluation process is summarized in Figure 9, and the detailed calculation process is described as follows.
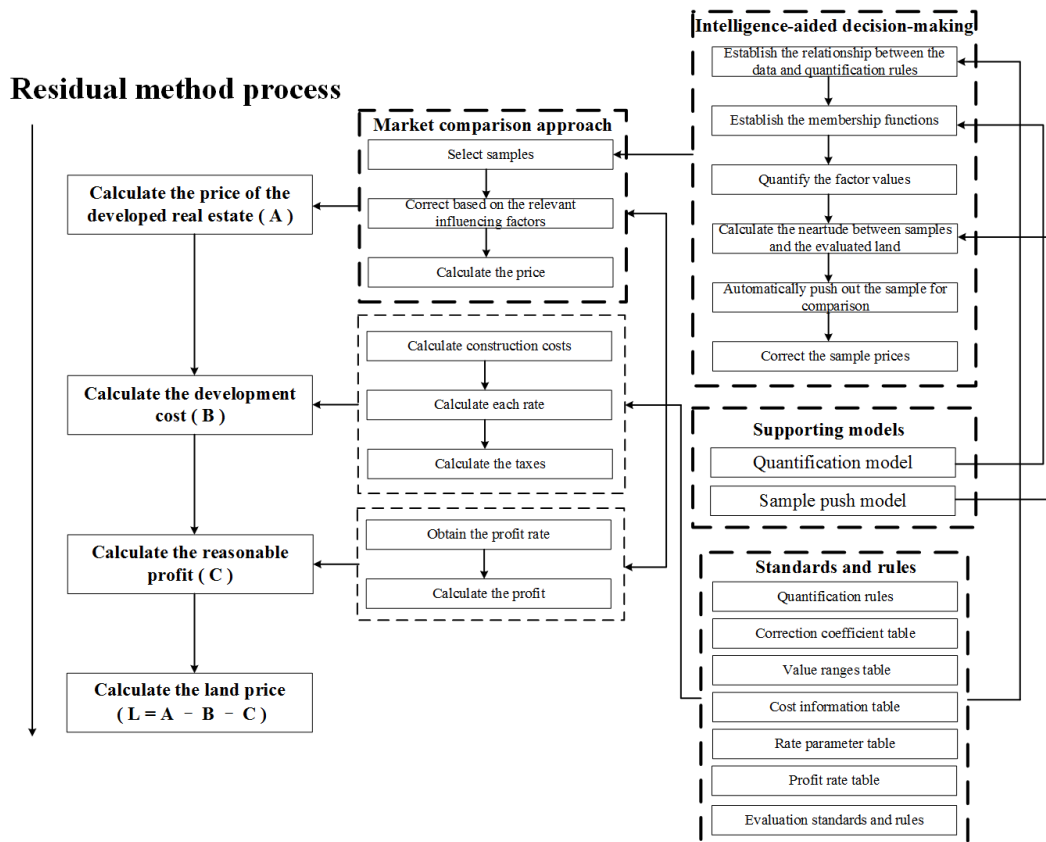

Figure 9. Evaluation process for the residual method supported by intelligence-aided decision-making.

3.2.1. Calculate the Real Estate Price, Supported by Intelligence-Aided Decision-Making

Step 1: Establish the relationships between the data and the quantification rules.

The quantification model establishes the relationships between the data and the quantification rules depending on the land use type. The weights representing the importance of the various factors in influencing the results have been confirmed by experts in Shenzhen.

To collect expert opinions in reference to the Delphi method, we selected expert appraisers with extensive experience in evaluating the land prices in Shenzhen, who have held their qualifications for a long time. We then performed the following steps:

(1)　Collected and analyzed related references from throughout the world.
(2)　Found case studies similar to Shenzhen.
(3)　Found experts who are specialized in research on the influence of location factors.
(4)　Designed a questionnaire similar to Table 1.
(5)　Posted the questionnaire online and sent the link of the website to the selected experts.
(6)　Requested the experts to fill in their own factors and weights.
(7)　Analyzed the received questionnaires and constructed a table similar to Table 1.
(8)　Sent the table to experts for review.
(9)　Iterated the above steps until all experts accepted the final table.

In our approach, we need to consider the uncertainty of factors and weights. This is necessary to adapt to the dynamic changes in data, rules and weights. For all lands in a given area, location factors tend to have similar effects because of their spatial similarity. In our case, experts selected 10 factor layers of interest based on spatial heterogeneity at a large scale [37], see Table 1 and Figure 10. The quantification model was applied to calculate the values of these location factors using the corresponding rules and weights.

1.　Central business district (CBD) accessibility at the city level: This layer refers to the accessibility of the CBD based on the division of the area into several grades at the city level. Locations of Grade 1 are in the lowest-cost areas, and locations of Grade 5 are in the highest-cost areas.
2.　CBD accessibility at the administrative district level: This layer refers to the accessibility of the CBD based on the division of the area into several grades at the administrative district level. Locations of Grade 1 are in the lowest-cost areas, and locations of Grade 5 are in the highest-cost areas.
3.　Urban rail station: This layer refers to the network distance to the nearest urban rail station.
4.　Park planning: This layer refers to the network distance to the nearest planned location of a park.
5.　Urban rail station planning: This layer refers to the network distance to the nearest planned location of an urban rail station.
6.　Main district planning: This layer refers to the spatial relationship with respect to a planned main district.
7.　Hospitals: This layer refers to the network distance to the nearest hospital.
8.　Primary school district: In China, primary school districts are classified by the quality of education.
9.　Middle school district: In China, middle school districts are classified by the quality of education.
10.　Green park space: This layer refers to the network distance to a green space, such as a park.

Table 1. Location factors, as confirmed by experts.

Location Factor	Measure	Rule	Weight
CBD Accessibility at the City Level	Spatial Position	If the Grade of area the land located is 1, the score is 100; If the Grade of area the land located is 2, the score is 95; If the Grade of area the land located is 3, the score is 90; If the Grade of area the land located is 4, the score is 85; If the Grade of area the land located is 5, the score is 80; Otherwise, the score is 80.	0.03
CBD Accessibility at the Administrative District Level	Spatial Position	If the Grade of area the land located is 1, the score is 100; If the Grade of area the land located is 2, the score is 95; If the Grade of area the land located is 3, the score is 90; If the Grade of area the land located is 4, the score is 85; If the Grade of area the land located is 5, the score is 80; Otherwise, the score is 80.	0.06
Urban Rail Station	Network Distance	If the distance to the nearest station is 0 m to 500 m, the score is 100; If the distance to the nearest station is 500 m to 1000 m, the score is 90; If the distance to the nearest station is more than 1000 m, the score is 80.	0.15
Bus Stations	Network Distance	If the distance to the nearest station is 0 m to 300 m, the score is 100; If the distance to the nearest station is 300 m to 500 m, the score is 90; If the distance to the nearest station is more than 500 m, the score is 80.	0.06
Park Planning	Network Distance	If the distance to the nearest planned park is 0 m to 1000 m, the score is 100; If the distance to the nearest planned park is over 1000 m, the score is 90.	0.02
Urban Rail Station Planning	Network Distance	If the distance to the nearest planned station is 0 m to 1000 m, the score is 100; If the distance to the nearest planned station is more than 1000 m, the score is 90.	0.02
Main District Planning	Spatial Position	If the land is in the planned district, the score is 100; If the land is outside of any planned district, the score is 90.	0.02
School Planning	Spatial Position	If the land is in a planned district, the score is 100; If the land is outside of any planned district, the score is 90.	0.02
Disadvantageous Facility Planning	Buffer Distance	If the distance to the nearest facility is 0 m to 1000 m, the score is 80; If the distance to the nearest facility is more than 1000 m, the score is 100.	0.02

Table 1. *Cont.*

| Location Factor	Measure	Rule	Weight
Hospitals	Network Distance	If the distance to the nearest hospital is 0 m to 500 m, the score is 90; If the distance to the nearest hospital is 500 m to 2000 m, the score is 100; If the distance to the nearest hospital is more than 2000 m, the score is 80.	0.06
Kindergartens	Network Distance	If the distance to the nearest kindergarten is 0 m to 1000 m, the score is 100; If the distance to the nearest kindergarten is more than 1000 m, the score is 90.	0.06
Primary School District	Spatial Position	If the Grade of district the land located is 1, the score is 100; If the Grade of district the land located is 2, the score is 90; If the Grade of district the land located is 3, the score is 80.	0.06
Middle School District	Spatial Position	If the Grade of district the land located is 1, the score is 100; If the Grade of district the land located is 2, the score is 90; If the Grade of district the land located is 3, the score is 80.	0.12
Green Park Space	Network Distance	If the distance to the nearest park is 0 m to 1000 m, the score is 100; If the distance to the nearest park is 1000 m to 4000 m, the score is 90; If the distance to the nearest park is more than 4000 m, the score is 80.	0.2
Seascape and Mountain Scenery	Buffer Distance	If the distance to the nearest scenic location is 0 m to 1000 m, the score is 100; If the distance to the nearest scenic location is more than 1000 m, the score is 80.	0.1
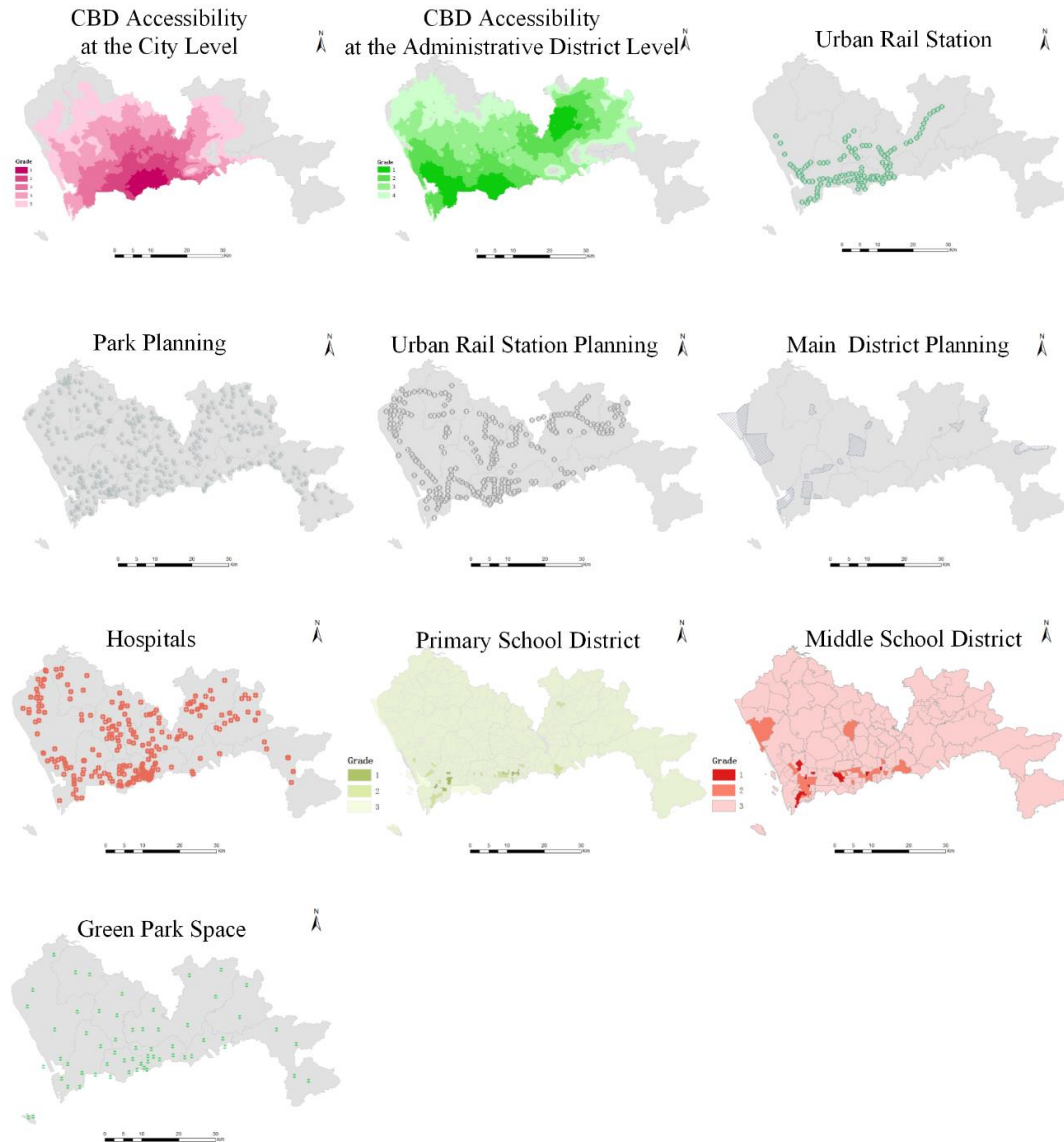
Figure 10. Layer services provided by the government.

Step 2: Establish the membership functions.

The model establishes membership functions based on the fuzzy rules that are defined for each factor. For example, for the hospitals factor,

$$V(d) = \begin{cases} 90, (d \leqslant 500) \\ 100, (500 < d \leqslant 2000) \\ 80, (d > 2000) \end{cases} \qquad (8)$$

$$V(d) = 90 > V(d) = 100 > V(d) = 80 \qquad (9)$$

Here, d in Equation (8) is the network distance between the land and the nearest hospital. Equation (9) means that when assessing the hospitals factor, the condition of $V(d) = 90$ should be checked first, followed by $V(d) = 100$ and then $V(d) = 80$. The final result is decided by the condition with the highest priority.

Step 3: Quantify the factor values.

The proposed quantification model obtains the information for the closest facility. In the tables below, the numbers in the header correspond to the factors listed above. From Table 2, we find that the land we selected for the case study is located in an area with Grade 3 CBD accessibility at the city level, Grade 2 CBD accessibility at the administrative district level, a distance of 784 m to the nearest urban rail station, a distance of 835 m to the nearest planned park, a distance of 766 m to the nearest planned urban rail station, a location outside of any planned main district, a distance of 1146 m to the nearest hospital, a primary school district of Grade 3, a middle school district of Grade 3 and a distance of 2864 m to the nearest green park space.

Table 2. The values calculated using the relationships between the factors and land prices.

	1	2	3	4	5	6	7	8	9	10
Case	3	2	784 m	835 m	766 m	out	1146 m	3	3	2864 m
Sample 1	3	3	577 m	888 m	595 m	out	1628 m	3	3	2773 m
Sample 2	3	3	604 m	915 m	622 m	out	2135 m	3	3	2114 m
Sample 3	3	3	483 m	794 m	501 m	out	1899 m	3	3	2679 m
Sample 4	3	2	1387 m	1438 m	1369 m	out	1245 m	3	3	3466 m
Sample 5	3	3	286 m	2377 m	735 m	out	535 m	3	3	3560 m
Sample 6	3	3	330 m	2421 m	690 m	out	579 m	3	3	3604 m
Sample 7	3	3	1538 m	1829 m	1258 m	out	632 m	3	3	3857 m
Sample 8	3	3	248 m	2338 m	988 m	out	497 m	3	3	3522 m
Sample 9	3	3	1285 m	841 m	2270 m	out	1044 m	3	2	1515 m
Sample 10	3	3	90 m	2600 m	90 m	out	1024 m	3	3	4556 m

The results of calculating the quantitative values for the factors are shown in Table 3.

Table 3. The quantitative factor values calculated according to the defined rules.

	1	2	3	4	5	6	7	8	9	10
Case	90	95	90	100	100	80	100	80	80	90
Sample 1	90	90	90	100	100	80	100	80	80	90
Sample 2	90	90	90	100	100	80	80	80	80	90
Sample 3	90	90	100	100	100	80	100	80	80	90
Sample 4	90	95	80	90	90	80	100	80	80	90
Sample 5	90	90	100	90	100	80	100	80	80	90
Sample 6	90	90	100	90	100	80	100	80	80	90
Sample 7	90	90	80	90	90	80	100	80	80	90
Sample 8	90	90	100	90	100	80	90	80	80	90
Sample 9	90	90	80	100	90	80	100	80	90	90
Sample 10	90	90	100	90	100	80	100	80	80	80

Step 4: Calculate the neartudes between the samples and the evaluated land.

In the sample push model, the location factors of the samples are treated as fuzzy sets, and the neartudes are calculated using the maximum-minimum closeness method. The results for the similarities between the case study land and the samples are shown in Table 4. A value closer to one indicates greater similarity.

Table 4. The quantitative degrees of similarity between the samples and the evaluated land.

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Neartude:	0.9954476	0.9772382	0.9732937	0.9711684	0.9703264
	Sample 6	**Sample 7**	**Sample 8**	**Sample 9**	**Sample 10**
Neartude:	0.9703264	0.9666160	0.9614243	0.9523099	0.940652

Step 5: Automatically push out the samples for comparison.

The neartude results are sorted and used to filter the samples by rank. The samples pushed out by the computer can then be considered to be the samples that are most similar to the land to be evaluated. We select Samples 1, 2, and 3 as the samples to be used to calculate the real estate price.

Step 6: Correct the prices of the samples, and calculate the real estate price.

The prices of the samples cannot be directly used to evaluate the real estate price for the evaluated land. These prices should be corrected according to the indices given in the standard files provided by the government. The evaluated real estate price (A) in this case is 26,623.67 RMB per square meter (RMB is the abbreviation for renminbi yuan, which is the monetary unit in China; 1 RMB is equivalent to approximately $0.1522 at current exchange rates).

3.2.2. Calculate the Land Price

The cost of development (B) and developer profits (C) can be calculated according to the real estate price and the government standards. The data used to calculate B and C can be obtained from the web services provided by the appropriate governmental departments to ensure that the data are dynamic. The final land price is found to be $V = A - (B + C) = 14,038.97$ RMB per square meter, which can be multiplied by the area of the land to find the total price of the land.

4. Conclusions

The approach proposed in this paper replaces the conventional desktop-based land price evaluation process with one based on a web browser. Online data source sharing is exploited to solve the problems faced by appraisers because they are always lacking data and are obliged to collect many updated data before performing an evaluation. The process is done similarly to that of online order handling assisted by the tools provided by the system.

The price calculated in our chosen case study was similar to the real price, indicating that the proposed approach for the establishment of an online land price evaluation system should simplify the work required of appraisers on the condition that the entire process complies with national standards. In the conventional evaluation process, an appraiser relies primarily on experience-based knowledge and manual calculations. Many factors influence land prices, and these factors can be considered to compose fuzzy sets. The GIS- and fuzzy set-based location factor quantification model proposed in this paper measures "similarity" based on a qualitative method to achieve quantification. Moreover, the introduced quantification measure based on network distance is more representative of travel habits than a measure based on the direct distance. The neartude-based transaction sample push model proposed in this paper ranks the similarities between samples and the land to be evaluated and pushes out the most similar samples to assist in decision-making. The innovation and improvement offered by our online evaluation approach will make land price evaluations more efficient and the results more reliable.

The application of our approach to the city considered in our case study demonstrates that the proposed approach makes land price evaluations more convenient and efficient for appraisers. It builds connections between users and data and assists appraisers in their evaluations by making full use of fuzzy set theory and GIS techniques. The ability to use a variety of data available through web services in the analysis can reduce the necessary paperwork, the cost of collecting information, the complexity of calculation and the influence of subjective judgement. This automation of land price evaluations will improve the land price evaluation environment in Shenzhen by virtue of its successful integration of information. Moreover, such data support is also expected to be beneficial in other regions. The proposed approach will be useful for building a standard evaluation workflow for all governmental organizations in China. It will allow every step of the process to be more scientific and to be recorded for verification. In summary, the proposed method of automated land price evaluation is expected to be of general benefit.

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