Land suitability evaluation for development using a matter-element model: A case study in Zengcheng, Guangzhou, China

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\textbf{ABSTRACT}

Land suitability evaluation can assist in the efficient use of land resources at a regional level. This is an important issue because of the pressures that an increasing population and economic growth have put on limited land resources. Matter-element theory, which was first put forward by the Chinese mathematician Cai Wen, has shown potential for solving incompatibility problems. Based on the matter-element model, this paper uses land use, roads, water bodies, population density, distance from center of the city, geodetic height, and slope as factors in modeling land suitability for development. Zengcheng, an urban–rural administration was used as a case study for applying the matter-element model to assessing the suitability of land for development. The model was cross referenced with local urban plans for verification and the results of this study show that the model constructed was effective at assessing the suitability of land for development. According to both the classification map created using the matter-element model and the statistics on the of land suitability classes, the study area was found to have a considerable amount of land which is highly suitable for development. After the category 'highly suitable', the next largest total land area was in the category of 'not suitable' for development, while there was relatively little land classified as moderately and marginally suitable. The percentage of the total land area of each class of suitability was 41.80%, 34.22%, 16.33% and 7.64%, respectively. Apart from this, the study also demonstrated the advantage of matter-element models over fuzzy theory, as they provide much more information. For example, all integrated degree of all classes in the paper had ranges from –1 to 1, but differed from each other by percentage. In the category of ‘highly suitable’ only 45.51% of matter-elements fully conformed to the criteria (those within a range of 0–0.5925), while the remainder (54.49%) did not corresponded to the requirements of the category, but did have the potential to do so with relatively few changes (those within a range of –0.3923–0 degrees). This data provides us with an understanding of the potential and limitation to development of the land in the region.

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\textbf{Introduction}

Owing to economic and demographic growth, there has been abundant urban expansion and related construction in China (Long et al., 2007, 2008, 2009, 2011). This has resulted in major changes to the urban landscape and to human and natural systems, both globally and regionally (Solecki, 2001; Kamusoko et al., 2009). This in turn has resulted in environmental problems such as a scarcity of land resources and urban heat islands (Stephan et al., 2005; Stevens et al., 2007; Poelmans et al., 2010). This environmental damage may be reduced in developing countries and regions by utilizing the land more effectively. With careful planning, land use could be managed to meet the demands of development with minimal destruction of ecosystems in the future.

Land suitability means the suitability of a given type of land to support a defined land use, either in its current state or after improvements. Land suitability evaluation means the process of appraisal and grouping of specific areas of land in terms of their suitability for defined uses (Liu et al., 2006). This assessment is always carried out separately for each category of land use (Reshmidevi et al., 2009). With the urgent pressures of economic development, urban land-use change is frequent and inevitable. Thus the importance of evaluating land suitability in urban areas is apparent. Land suitability evaluation can assist in assigning land resources to appropriate uses, shape (or reshape) urban development to create
a well laid-out urban environment, and both directly or indirectly alleviate the negative effects of development on ecosystems (Nuissl et al., 2009). Evaluation of land suitability for development is also essential for planners to identify the optimal areas for construction, which depicts the spatial heterogeneity of land and is the core data on which of land management and land-use planning are based (Collins et al., 2001).

In China, as in other developing countries, a growing proportion of the population lives in cities, many of cities are growing more than million peoples, where a large intergradation zone is the rural–urban zone (Addo, 2010). This has resulted in increasing land transformation, predominantly from farm land to commercial/constructed land (Sullivan and Lovell, 2006; Thapa and Murayama, 2008). There has been a lot of research in the field of land-use assessment in order to determine the optimal distribution of land use/cover (Fontes et al., 2009). However, land suitability evaluation characteristics vary between regions, and to be practical, they must not become overly complicated.

Guangzhou, as other cities in China, has experienced significant increases (between 30 and 50%) in urban area over the last 15 years (Yu and Ng, 2007). The case study area is an administrative district in Guangzhou, Zengcheng (a detailed description is included in the study area section). Taking matter-element models as the analytic method, this paper aims to explore their effectiveness in land suitability evaluation, to identify the potential areas of land suitable for development, and to appraise the model by overlaying the resulting map on the local planning blueprint. The resulting map will be of value in future urban planning decisions.

Land suitability evaluation models based on matter-element theory

Matter-element theory was first introduced for solving incompatible problems in the 1980s by the Chinese mathematician Cai Wen (Cai, 1994; Cai et al., 2000). Since then matter-element theory has been applied not only to mathematics but also system theory, noetic science, and a number of other disciplines. New methods of system matter-element analysis were created and adapted to suit its applications in system theory. Systems were considered as a set of matter-elements, with each element consisting of objects, characteristics and values which participate in a range of processes and transformations (Jiang et al., 2000; Tang et al., 2009). Following on from this idea, matter-element analysis now includes the following basic steps: firstly, the system is divided into matter-elements (objects). Analysis or evaluation factors are then selected and classes are defined. Class intervals for each factor are then also defined. For each class the range of values is called the classical domain, while the whole range of values for all classes is called the segmented domain. Thirdly, the correlation degree for each single factor (in other words how well each factor matches the criteria for the category) is calculated. Finally, the integrated correlation degree of matter-elements for each class is calculated through model integration methods such as the weighted average method. The class (which includes the maximum integrated correlation degree) defines the grade the matter-element falls within.

While \( L \) is depicted by \( n \) characters, \( R \) would be expressed as follows (Tang et al., 2009):

\[
R = (M, c, V) = \begin{bmatrix} M \; c_1 \; v_1 \\
C_2 \; C_2 \; v_2 \\
\vdots \; \vdots \; \vdots \\
C_j \; C_j \; v_j \\
\vdots \; \vdots \; \vdots \\
C_n \; C_n \; v_n \end{bmatrix} \quad (j = 1, 2, \ldots, n)
\]

where \( R \) is \( n \)-dimensional matter-element of land suitability for development, \( M \) is land suitability, \( c \) is the characteristic of the matter-element, and \( V \) is the values of \( c \).

Classical domain and segmented domain of matter-element for land suitability

Segmented domain of matter-element means the ranges of values the characteristic \( j \) might take (Tang et al., 2008). For \( c_j \) in formula (1), supposed that \( v_j \) ranged from \( a_{pj} \) to \( b_{pj} \), the segmented domain of matter-element for land suitability would be the interval \( a_{pj} \sim b_{pj} \) and the end value at double points. Correspondingly, the matrix of the segmented domain could be as follows:

\[
R_p = (M_p, c, V_p) = \begin{bmatrix} M_p \; c_{p1} \; (a_{p11}, b_{p11}) \\
M_p \; c_{p2} \; (a_{p22}, b_{p22}) \\
\vdots \; \vdots \; \vdots \\
M_p \; c_{pj} \; (a_{pj}, b_{pj}) \\
\vdots \; \vdots \; \vdots \\
M_p \; c_{pn} \; (a_{pn}, b_{pn}) \end{bmatrix} \quad (2)
\]

where \( R_p \) represents the matter-element of the segmented domain. \( M_p \) and \( V_p \) mean the same as \( M \) and \( V \) but apply to the segmented domain.

The classical domain of matter-element means the range of values the characteristic \( j \) might take in each class \( i \). Thus, if \( L \) has \( t \) classes of land suitability, the value \( v_i \) of characteristic \( c_j \) would be divided into \( t \) intervals, each of which would include the interval \( a_{cij} \sim b_{cij} \). Then the matrix of the classical domain could be as follows:

\[
R_{ci} = (M_{ci}, c, V_{ci}) = \begin{bmatrix} M_{ci} \; c_1 \; (a_{c11}, b_{c11}) \\
M_{ci} \; c_2 \; (a_{c22}, b_{c22}) \\
\vdots \; \vdots \; \vdots \\
M_{ci} \; c_j \; (a_{cij}, b_{cij}) \\
M_{ci} \; c_n \; (a_{cin}, b_{cin}) \end{bmatrix} \quad (3)
\]

where \( R_{ci} \) is the matrix of the classical domain, \( i \) is the number of classes ranging from 1 to \( t \). \( M_{ci} \) is land suitability subjected to class \( i \), and \( V_{ci} \) is the value of characteristic in class \( i \). In values \( a_{cij} \sim b_{cij} \), the minimum of \( a_{cij} \sim b_{cij} \) equals \( a_{pj} \) in formula (2), while the maximum equals \( b_{pj} \).
Matter-element of land suitability for the object studied

For the study area, the matrix of the matter-element \((R_x)\) of the land suitability evaluation is expressed as follows (the footnote \(x\) represents the object studied):

\[
R_x = (M_x, c, V_x) = \begin{bmatrix}
M_x & c_1 & \nu_1 \\
& c_2 & \nu_2 \\
& \vdots & \vdots \\
& c_j & \nu_j \\
& \vdots & \vdots \\
& c_n & \nu_n \\
\end{bmatrix}
\]

(4)

Correlation degree between each factor and evaluation class

Based on the classical domain and the segmented domain, the degree of correlation between each characteristic and each class was calculated using the following functions:

\[
K(X_j) = \left\{ \begin{array}{ll}
\frac{-\rho(X_j, X_{cij})}{|X_{cij}|} & X_j \in X_{cij} \\
\frac{\rho(X_j, X_{cij}) - \rho(X_j, X_{ip})}{\rho(X_j, X_{cij})} & X_j \neq X_{cij}
\end{array} \right.
\]

(5)

where \(\rho(X_j, X_{cij})\) indicates the correlation degree between characteristic \(j\) and class \(i, X_j, X_{cij}\), and \(X_{ip}\) represent the value of the matter-element measured, range of the classical domain and the range of the segmented domain respectively. \(\rho(X_j, X_{cij})\) and \(\rho(X_j, X_{ip})\) represent the range of values from the classical domain and from the segmented domain, respectively.

Correlation degree between each matter-element object and evaluation class

The integrated correlation degree between each matter-element and evaluation class was essential to understanding the object in context. Following the general weighted average method, the integrated correlation degree of each matter-element was calculated thus:

\[
K_i(M_x) = \sum_{j=1}^{n} a_j K(X_j)
\]

(8)

where \(K_i(M_x)\) indicates the integrated correlation degree between matter-element object \((M_x)\) and evaluation class \(i, a_j\) is the weighted value of characteristic \(j\) with \(\sum_{j=1}^{n} a_j = 1\) \((j = 1, 2, \ldots, n)\). \(M_x\) belongs to class \(i\) while \(K_i(M_x) = \max[K(X_j)]\).

A case study in Zengcheng

Zengcheng (a typical area connecting municipal urban and rural zones) was selected as the location for this case study. To evaluate land suitability for development, the geography of the land surface, available types of land use, transportation and population should all be considered. Methods of using raster data in the models were adopted for all factors.

Study area

Zengcheng is located in the Pearl River Delta in eastern Guangzhou. It covers an area of approximately 1616.47 km² (OWZM, 2010). This is 23% percent of Guangzhou’s total area. It extends from 23°4’42” to 23°37’20”N in latitude, and from 113°29’4” to 113°59’44”E in longitude. It has a southern tropical oceanic monsoon climate with abundant sunshine and rainfall, an average annual temperature of 22.2°C and an average annual precipitation of 1869 mm (ideal for plant growth). Zengcheng is also known as the ‘Town of Lychee’ and ‘Town of Rice and Fish’, due to its abundance of natural resources.

The topography is characterized by mountains and hills with the Zengjiang River crossing through the area from north to south, then finally meeting the Pearl River (Fig. 1).

One of the administrative districts of Guangzhou, Zengcheng, is typical of rural–urban fringe zones. It is 60 km from Guangzhou, 120 km from the Shenzhen Special Zone, and 129.64 km from Hong Kong.

In the last 20 years Zengcheng has been undergoing sustainable development in the local financial, economic, and social sectors, thereby maintaining a period of prosperity and stability. This development has led to a significant change in the appearance of the city, while at the same time creating a bottleneck in its continuing development, as land becomes less and less available (Zheng et al., 2007). The local government has taken active steps to address this issue; for example the creation of a fixed-period urban master plan focused on local development. Over the past decade (2001–2010) Guangzhou has had urban master plans for
the periods 2001–2010 and 2010–2020. An urban master plan for Zengcheng was also developed for both periods. In the first stage (2001–2010), Zengcheng implemented an innovative approach to intra-county economic development, termed the ‘Zengcheng Mode’. The latest urban master plan for Zengcheng was drawn up in 2008. It promotes a series of schemes that are aimed to integrate social effectiveness, economic benefits, eco-environment effectiveness, and to optimize regional urban space, thereby facilitating local sustainable development. The land-use plan featured quantity and distribution of land as an indispensable key component. Nevertheless, exploring and improving on the efficiency of this plan remains basic, and evaluating land suitability for development is the first step needed to do this.

**Land-use structure in 2009**

Landsat 5 Thematic Mapper images were used in this study (mesoscale resolution; images taken on 2 January 2009). The World Reference System (WRS) number of the images used is 122/04385, corresponding to one general scene comprising 85% of WRS 122/044 and 15% of WRS 122/043. The nominal spatial resolution was 30 m. A 1:50,000 topographic map compiled by the Guangzhou Institute of Surveying and Drawing in 1984 was used to rectify the TM images.

Using the images and the topographic map, the TM image was first rectified with the root-mean-square difference controlled to be less than 1m. The unified projected coordinate system was the Universal Transverse Mercator (UTM) projection with an original longitude of 111°E, original latitude 0°N, WGS84 geodetic datum, and WGS84 ellipsoid. Following this the land-use structure map was derived from TM images employing a user–computer interactive interpreting method, and a ground-truthing field survey was carried out to check that points on the map corresponded with real position on the ground. The accuracy of land-cover classification was found to be 76.1%. Fig. 2 shows the land-use structure map, with seven classes adopted: paddy fields, orchard fields, forested land, construction land, transportation land, water bodies, and other land.

It can be seen from the graph that Zengcheng is a region with a high proportion of vegetation cover,(mostly distributed throughout the northern regions). Orchard and crop land comprise a significant portion of the study area, particularly in the central and the southeastern regions, although discrete enclaves exist throughout. The urban areas are located primarily in the southwestern and central eastern areas of the city.

**Roads and water body and construction land**

A full description of transportation and construction land is available in Fig. 3. Both land-use categories are prevalent in densely populated areas in the central southern region of Zengcheng, including four towns: Xintang, Shitan, City Center and Zhongxin. Additionally, the national economic development zone of Zengcheng is located in Xintang town (according to the master plan). Fig. 3a also shows that water bodies are distributed discretely, with the exception of the Zengjiang River, which runs across the region.

**Terrain and slope**

The topography of the study area is depicted in Fig. 4, part one of which is a contour map, the other part a slope map. The contour map shows that the terrain is mainly at a low elevation (in white) with most areas less than 60 m in altitude. Terrain in black (which indicates elevations higher than 200 m) comprises a relatively small area. The slope map shows that the surface of the area is very uneven, with slope values of >15° taking up the greatest percentage of area.

**Population density**

Different population densities have different effects on land suitability for development. Therefore population density was considered as an independent variable in this model. Data were acquired from the latest urban master plan for Zengcheng, which was drawn up in 2008 by the local government.

Using ArcGIS tools (Spatial Statistics Tools/Measuring Geographic Distributions/Mean Center), the geographic centers (concentrations of population) were obtained for seven towns and villages (Fig. 3b) and a centroid layer was created. From this the population density distribution layer was derived.

**Important contents on land use in the urban master plan (2010–2020)**

According to the urban master plan (2010–2020), the area has already been divided into three Economic Circles (shown in Fig. 5, region enclosed by blue curve, respectively). The northern area was designated as an Ecological Industrial Circle (EIC), which addresses the development objectives of urban agriculture, ecotourism, culture. The southern area will become increasingly focused on advanced manufacturing industries (named Advanced Manufacturing Industrial Circle, AMIC), while the central areas should become mainly residential (Residential Circle, RC).

Besides three Economic Circles, the graph displayed any special land use designated from urban plan blueprint, including reserved land for development, planned land for green channel and for rail transit.

**Matter-element model of land suitability evaluation for development**

**Evaluation factors and weights**

In this study seven factors were derived based on a study of relevant literature (Dumanski and Pieri, 2000; Huang et al., 2010; Liu et al., 2010) and regional features were used to evaluate land suitability for development. They were land use, roads, water bodies, population density, distance from the center of the city, geodetic height and slope. Data on each of these factors was sampled with a grid size of 10 m × 10 m, and standardized to a common UTM projected coordinate system. ArcGIS9.2 and Erdas Image 9.1 software were used.
An integrated method combining domain experts and an analytic hierarchy process (AHP) was adopted to obtain the relative significance values \( a_j \) of factors contributing to the suitability of land for development (Table 1).

**Land suitability classes and the criteria**

Land suitability classes reflect quantitatively the degree of suitability. In accordance with human preference three classes were adopted: *Highly suitable* (having no significant limitations to development, or only minor limitations within an acceptable category), *Moderately suitable* (having limitations which are moderately severe and within a moderately acceptable category), and *Marginally suitable* (having major limitations). The class *Not suitable* is used for all other area (Bydekerke et al., 1998; Thapa and Murayama, 2008). The four classes used here are shown below in Table 2. The correspondingly descriptions of each class were defined from previously published literatures (Liu, 2000; Ge et al., 2009; Wang et al., 2009).

**Normalization for measurement factors**

Measurements of all factors were normalized using the efficacy coefficient method for each class defined, the formula for which is

\[
S(x_j) = S_{MIN} + \frac{x_j - \min(x_j)}{\max(x_j) - \min(x_j)} \times (S_{MAX} - S_{MIN}),
\]

while \( x_j \) is a positive effective factor

**Table 1**

<table>
<thead>
<tr>
<th>Factors</th>
<th>Population density (PD)</th>
<th>Distance from transportation (DTS)</th>
<th>Distance from Water body (DWE)</th>
<th>Distance from city center (DCC)</th>
<th>Terrain (TE)</th>
<th>Slope (SL)</th>
<th>Land use (LU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( x_j )</td>
<td>( x_1 )</td>
<td>( x_2 )</td>
<td>( x_3 )</td>
<td>( x_4 )</td>
<td>( x_5 )</td>
<td>( x_6 )</td>
<td>( x_7 )</td>
</tr>
<tr>
<td>Weights</td>
<td>0.121</td>
<td>0.369</td>
<td>0.108</td>
<td>0.195</td>
<td>0.06</td>
<td>0.06</td>
<td>0.1</td>
</tr>
</tbody>
</table>
or

\[ S(x_y) = S_{\text{MIN}} + \frac{\max(x_{y}) - x_y}{\max(x_{y}) - \min(x_{y})} \times (S_{\text{MAX}} - S_{\text{MIN}}), \]

where \( x_y \) is a negative effective factor

where \( S(x_y) \) is the normalized value of \( x_y \), ranging from 0 to 100, \( S_{\text{MAX}} \) is the maximum standard value of a defined class which \( x_y \) belongs to and \( S_{\text{MIN}} \), the corresponding minimum (such as 100 and 80), while \( x_y \) is subjected to the highly suitable class (in Table 2). For the same class, \( \max(x_{y}) \) and \( \min(x_{y}) \) are measurements of the maximum and minimum of all matter-elements, respectively. For example, DTS in the highly suitable class \( \max(x_{y}) \) equals 100 while \( \min(x_{y}) \) equals 0.

**Classical domain, segmented domain**

According to the original concept of matter-element model (Cai et al., 2000), the original applications of this process (Tang et al., 2009), and the references for each of the categories of suitability (Huang et al., 2010), segmented domain \( (R_p) \) and classical domain \( (R_{ci}) \) were established as follows:

\[ M_p c_1 \begin{array}{c} (0, 100) \end{array} \]
\[ M_p c_2 \begin{array}{c} (0, 100) \end{array} \]
\[ M_p c_3 \begin{array}{c} (0, 100) \end{array} \]
\[ M_p c_4 \begin{array}{c} (0, 100) \end{array} \]
\[ M_p c_5 \begin{array}{c} (0, 100) \end{array} \]
\[ M_p c_6 \begin{array}{c} (0, 100) \end{array} \]
\[ M_p c_7 \begin{array}{c} (0, 100) \end{array} \]

\[ R_p = (M_p, c, V_p) = \]

\[ R_{ci} = (M_{ci}, c, V_{ci}) = \]

All symbols have the same meaning as has been previously described. Thus \( a_{ci}, b_{ci} \) (i equals to 1–4) has a value corresponding to that in Table 2.

**Matter-element of evaluation object**

As all raster-based maps sampled grids (in this case with 10 m × 10 m pixels), the study area was divided into many matter-elements, each of which is considered an evaluation object (matter-element). While the centroid in the study area was taken as an example, the matter-element of the evaluation object is expressed as follows:

\[ M_x c_1 \begin{array}{c} 100 \end{array} \]
\[ M_x c_2 \begin{array}{c} 34.5978 \end{array} \]
\[ M_x c_3 \begin{array}{c} 100 \end{array} \]
\[ M_x c_4 \begin{array}{c} 33.1694 \end{array} \]
\[ M_x c_5 \begin{array}{c} 39.7251 \end{array} \]
\[ M_x c_6 \begin{array}{c} 49.1264 \end{array} \]
\[ M_x c_7 \begin{array}{c} 60 \end{array} \]

where the subscript center represents the matter-element in the centroid of the study area. Other characters continue as has been previously described.

**Suitability evaluation of land for development**

**Land suitability evaluation**

Land suitability for development was calculated using matter-element models. Following this, the correlation degree between each index and class was calculated using formulae (5)–(7) for the matter-element of the centroid. Correspondingly, the integrated correlation degree of the matter-element was then calculated using formula (8).

The results are presented in Table 3. The integrated correlation degrees were −0.10055, −0.25730, −0.40582, and −0.50334. These

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**Table 2**

Land suitability classes and quantitative criteria for development.

<table>
<thead>
<tr>
<th>Classes (L)</th>
<th>PD (person/km²)</th>
<th>DTS (m)</th>
<th>DWB (m)</th>
<th>DCC (m)</th>
<th>TE (m)</th>
<th>SL (°)</th>
<th>LU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highly suitable</td>
<td>( x_{ij} )</td>
<td>&gt;1086.6</td>
<td>&lt;100</td>
<td>&gt;200</td>
<td>&lt;100</td>
<td>&lt;60</td>
<td>&lt;7</td>
</tr>
<tr>
<td>Moderately suitable</td>
<td>( a_{ij}, b_{ij} )</td>
<td>(80, 100)</td>
<td>[1000, 2000]</td>
<td>(140, 200)</td>
<td>[1000, 2000]</td>
<td>[60, 100]</td>
<td>[7, 15]</td>
</tr>
<tr>
<td>Marginally suitable</td>
<td>( a_{ij}, b_{ij} )</td>
<td>(691.2, 1086.6)</td>
<td>[2000, 3000]</td>
<td>[100, 140]</td>
<td>[2000, 4500]</td>
<td>[100, 200]</td>
<td>[15, 25]</td>
</tr>
<tr>
<td>Not suitable</td>
<td>( a_{ij}, b_{ij} )</td>
<td>(0, 40)</td>
<td>3000</td>
<td>≥100</td>
<td>≥4500</td>
<td>≥200</td>
<td>≥25</td>
</tr>
</tbody>
</table>

Note: PD, DTS, DWB, DU, TE, SL and LU are abbreviations of population density, distance from transportation, distance from water body, distance from city center, terrain, slope and land use.

---

**Fig. 5.** Special land use and three Regional Economic Circles in urban plan blueprint.
Table 3
Correlation degree between each index and evaluation class.

<table>
<thead>
<tr>
<th>Classes</th>
<th>PD (person/km²)</th>
<th>DTS (m)</th>
<th>DWB (m)</th>
<th>DU (m)</th>
<th>TE (m)</th>
<th>SL (%)</th>
<th>LU</th>
<th>Integrated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highly suitable</td>
<td>0</td>
<td>-0.56753</td>
<td>0</td>
<td>-0.58538</td>
<td>-0.50344</td>
<td>-0.3859</td>
<td>-0.3333</td>
<td>-0.40582</td>
</tr>
<tr>
<td>Moderately suitable</td>
<td>-1</td>
<td>-0.42337</td>
<td>-1</td>
<td>-0.447177</td>
<td>-0.37392</td>
<td>-0.18123</td>
<td>0</td>
<td>-0.50334</td>
</tr>
<tr>
<td>Marginally suitable</td>
<td>-1</td>
<td>-0.13506</td>
<td>-1</td>
<td>-0.170766</td>
<td>-0.00688</td>
<td>0.912638</td>
<td>0</td>
<td>-0.25730</td>
</tr>
<tr>
<td>Not suitable</td>
<td>-1</td>
<td>0.27011</td>
<td>-1</td>
<td>0.341532</td>
<td>0.013745</td>
<td>-0.15667</td>
<td>-0.3333</td>
<td>-0.10055</td>
</tr>
</tbody>
</table>

Table 4
Area and percentage of different suitable class.

<table>
<thead>
<tr>
<th>Classes of suitability</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highly suitable</td>
<td>41.80</td>
</tr>
<tr>
<td>Moderately suitable</td>
<td>16.35</td>
</tr>
<tr>
<td>Marginally suitable</td>
<td>7.64</td>
</tr>
<tr>
<td>Not suitable</td>
<td>34.22</td>
</tr>
</tbody>
</table>

Table 5
Range of land suitability class and its percentage of sub-range.

<table>
<thead>
<tr>
<th>Correlation degree K(M_L)</th>
<th>Ranges</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(-0.25, 0)</td>
<td></td>
</tr>
<tr>
<td>Highly suitable</td>
<td>-0.3923 to 0.5925</td>
<td>3.99</td>
</tr>
<tr>
<td></td>
<td>18.78</td>
<td>17.03</td>
</tr>
<tr>
<td>Moderately suitable</td>
<td>-0.3783 to 0.3797</td>
<td>2.27</td>
</tr>
<tr>
<td></td>
<td>12.46</td>
<td>1.61</td>
</tr>
<tr>
<td>Marginally suitable</td>
<td>-0.3788 to 0.3535</td>
<td>13.88</td>
</tr>
<tr>
<td></td>
<td>76.24</td>
<td>9.83</td>
</tr>
<tr>
<td>Not suitable</td>
<td>-0.3922 to 0.4589</td>
<td>5.47</td>
</tr>
<tr>
<td></td>
<td>40.12</td>
<td>43.59</td>
</tr>
</tbody>
</table>

Note: Percentages on row 1 of each suitability class are calculated for the whole area, while that on row 2 (boldface type) are for just the corresponding class.

corresponded with the categories, Not suitable, Marginally suitable, Highly suitable and Moderately suitable (displayed in the last column in Table 3), respectively. Therefore, the matter-element belonged to suitability class Not suitable.

This study has demonstrated the suitability of the plan by overlaying the map layer of special land use, which was designated from urban plan blueprint, including reserved land for development, planned land for rail transit in urban plan blueprint (Fig. 5), on the sustainability class map created (Fig. 6). It can be seen that land reserved for future development overlaps with that categorized as highly suitable on the model’s map (red areas overlapping yellow). This demonstrates that the urban plan is appropriate, whereas, this coincidence also demonstrates that the model’s accuracy is acceptable.

Distribution of land suitable classes and statistics

One of the main outputs from this model is a classification map of land suitability classes. Suitable classes were calculated and the map depicting them is shown in Fig. 5. The study area was found to have a considerable amount of land suitable for development. Highly suitable areas are marked with yellow, and are located mostly in the southern central parts of the study area. Moderately and Marginally suitable areas are relatively fewer and more scattered throughout the study area. Aside from one isolated island in the central area, regions which were classified as Not suitable are located mostly in the northern and northeastern regions of the study area, and include the dense forests located there.

Table 4 presents the statistics which relate to Fig. 6. The percentage of area of each of the four suitability classes, including Highly, Moderately, Marginally and Not suitable accounted for 41.80, 16.35, 7.64 and 34.22% of the total area, respectively. Categorizing these regions into the four classes has made the quantity and location of areas with development potential in the study area clear. However, the class Not suitable (which covers areas that are mostly mountainous) was found to occupy 34.22% of the total land area, and more studies are needed to fully understand the limits to development potential in this region.

Ranges of land suitability classes

Table 5 shows the full range of values for each class of land suitability. In it we can see that the integrated degree of all classes ranged between -1 to 1 (e.g. -0.3923 to 0.5925 for the category Highly suitable, -0.3783 to 0.3797 for Moderately suitable, -0.3788 to 0.3535 for Marginally suitable, and -0.3922 to 0.4589 for Not suitable). Still we see that the matter-element analysis of each category yielded different results. For example, in the category Highly suitable, only 45.51% (40.75% + 4.76%) of matter-elements corresponded with the class and the correlation degree ranged from 0 to 0.5929, while the others (54.49%) which were not suitable, but had the potential to be developed ranged from -0.3923 to 0. When the whole area is taken into account, the former covered 19.02% (17.03 + 1.99) of the total area, and the latter 22.77% (3.99 + 18.78). Similarly, percentages of the class ‘Not
suitable’ were 54.41% (43.59 + 10.82) and 45.59% of the class respectively, while 18.62% and 15.60% of the total area. In both Moderately and Marginally suitable classes, the percentages of ranges ≥0 occupied only 9.88 and 29.04% of the class, respectively. Most ranges, however, were negative.

Discussion and conclusions

Matter-element theory, which was first introduced by a Chinese mathematician, has proven to be effective for solving incompatibility problems. Based on natural, social and economic characteristics, this paper looked at land use, roads, water bodies, population density, and distance from the center of the city, geodetic height and slope as factors to evaluate the land suitability for development using this theory. Zengcheng, an urban–rural administration, was taken as a case study area.

By overlapping the map of land suitability classes and the blueprint from the urban plan, the results showed that land reserved for future local development overlapped with that calculated to be in the class of Highly suitable in the overwhelming majority of instances. This indicates that matter-element models can be used in the evaluation of land suitability for development, and additionally cross referenced with local urban plans for verification.

According to the classification map and the statistics on land suitability classes, much of the study area is classed as Highly suitable for local development; however, there was also a considerable area which was found to be unsuitable for development. In comparison to these two classes, relatively little of the study area was classified as Moderately and Marginally suitable for development. For Highly suitable, Not suitable, Moderately and Marginally suitable, the percentage of the total area was 41.80%, 34.22%, 16.35% and 7.64%, respectively. Additionally, the results also demonstrated that most of the area classified as Highly suitable is located in the southern central areas of the region, while Not suitable areas were more scattered. However, most unsuitable areas were located in the northern and northeast regions, as well as an island in the center of the study area. A dense forest which covers the northern area provides an explanation of the limitation to development potential in this region.

This study also demonstrated that matter-element models provide much more information than fuzzy models provide. For example, the integrated degree of all classes had ranges from 1 to 1, which demonstrated that all suitability classes matter-element analysis results were relative, but different from each other by percentages. In the Highly suitable class only 45.51% of matter-elements corresponded to the class and, the correlation degree ranged from 0 to 0.5929, while the others (54.49%) which were not suitable for development but did have potential, ranged from 0.3923 to 0.

Although there has been a lot of work done on land suitability evaluation, more research is needed on modeling complex land resources, the dynamics of land and human systems, and overcoming other limitation of current knowledge. This paper explored matter-element analysis’s application in the field of land suitability evaluation and proved its effectiveness for the land system at the present. With the development of urban system, this could be therefore used to aid and improve land resource planning such as offering reference for a new round of general land-use planning.

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References


