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Original Article

Land use suitability analysis for town development planning in Nanjing hilly areas: A case study of Tangshan new town, China

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Abstract: Land use suitability analysis plays an important role in sustainable land use and solving environmental problems caused by rapid urban development. A land use suitability mapping approach for town development planning in hilly areas was constructed based on two multi-criteria evaluation methods: Weighted Linear Combination (WLC) and Ordered Weighted Averaging (OWA), to comparatively evaluate and map land use suitability of Tangshan new town in Nanjing, China. Fourteen evaluation factors related to topographic, environmental, socio-economics and historical sites data were used as suitability criteria. The analytic hierarchy process (AHP) method and GIS techniques were integrated into the evaluation models to create the land use suitability map for town development planning. The results of WLC approach showed that 11.4% of the total area is highly suitable while the 48.6% is unsuitable. The results of WLC and OWA approach showed the distribution of degree of land use suitability is almost the same. The areas located at the southern and eastern flat regions are highly suitable for land use, whereas the areas close to the mountain forests, steep slopes, waters, and hot springs, have lower suitability for land use. Sensitivity analysis indicated that the suitability results of the two proposed methods are robust. Indirect validation was achieved by mutual comparison of suitability maps derived from the WLC and OWA methods. It demonstrated that the overall agreement is 90.81% and kappa coefficient is 0.81, indicating that both methods provide very similar spatial suitability distributions. By overlaying the resultant map with the previous master plan map of Tangshan new town, the overlay map once again indicated a satisfactory ecological fit between the two maps. At last, several recommendations are proposed aiming at improving the long-term town development plan for Tangshan new town.

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1 Introduction

With the acceleration of urbanization and industrialization, land development has led to the degradation of the environment in many town areas with characteristics in China, such as the reduction of forest land and soil erosion (Nomura et al. 2018, Liu et al. 2019). How to coordinate the relationship between land development and ecological conservation has become a key issue for city planners and managers (Yong et al. 2010, Li et al. 2015, Karimi et al. 2018). In recent years, scientific and comprehensive land use suitability analysis has been recognized as a very important task to identify the most appropriate spatial pattern for future land use (Feizizadeh et al. 2013, Tang et al. 2015, Jiao et al. 2017).

Land use suitability analysis is the process of determining the eligibility of a certain land tract for a particular use according to specific requirements, preferences, or predictors of some activities (Pourebrahim et al. 2011, Memarbashi et al. 2017). With the support of geographical information system (GIS) technology, land use suitability analysis has implemented the transformation from qualitative to quantitative, and has been one of the most useful applications of GIS (Malczewski 2004, Liu et al. 2006, Liu et al. 2007). This suitability analysis has been applied to the assessment of landscape evaluation and planning (Herzog et al. 2001, Sakieh et al. 2017), agricultural land (Saygin et al. 2008, Kurtener et al. 2008), determination of land habitats for wildlife (Holzkamper et al. 2006, Mccluskey et al. 2018), and regional planning and environmental impact assessment (Kilic et al. 2003, Sakieh et al. 2015, Ruan et al. 2016).

With GIS platform, overlay mapping method can combine different types of information maps to help with better decision making regarding the suitability of land use for urban development (Schreier et al. 1983, Miller et al. 1998, Ayoade 2017). This method is routinely used in land use suitability analysis for urban development. While, it also has shortcomings, such as inappropriate criteria of land use evaluation for some special areas, unfit standardization of suitability maps, and untested or unverified assumptions of in-dependence among suitability criteria (Pereira et al. 1993; Batabyal 1998, Sandewall et al. 2001). To overcome these shortcomings, overlay mapping is often implemented in conjunction with other land use suitability analysis methods. In many case studies of land use suitability analysis, multi-criteria methods (MCE) have been used, including Weighted Linear Combination (WLC) (Shahabi et al. 2014, Aires et al. 2018), Ordered Weighted Averaging (OWA) (Malczewski 2006, Mokarram et al. 2011), Analytic Hierarchy Process (AHP) (Memarbashi et al. 2017, Hamzeh et al. 2016), the Ideal Point Method (IPM) (Sante-Riveira et al. 2008, Elaalem et al. 2011), the Land Suitability Index (LSI) Model (Joerin et al. 2001, Bandyopadhyay et al. 2009), the Ecological Niche Suitability Model (Zhao et al. 2015, Bajocco et al. 2016), and fuzzy-decision-making Trial and Evaluation Laboratory (F-DEMATEL) (Jin Su Jeong 2018). Although independence and uncertainty are taken into account, many in-depth discussions believe that MCE methods rely heavily on the input data, the choice of multi-criteria method or standardization method. With this in mind, it has been suggested that two or more multi-criteria methods should be implemented to mitigate the error of the suitability results (Carver 1991, Comber et al. 2012). Besides, a sensitivity analysis should be put into practice as part of the land use suitability analysis (Lodwick et al. 1990).

This paper proposed a land use suitability mapping approach for town development planning using overlay mapping in GIS platform combined with Weighted Linear Combination (WLC) and Ordered Weighted Averaging (OWA) approaches to generate suitability maps. The main objectives of this study are as follows: (1) To propose the multi-criteria system of land use suitability evaluation for town development planning, (2) Based on two multi-criteria evaluation methods: WLC and OWA, to comparatively evaluate and obtain the suitability map; to verify whether the suitability results of the two methods are robust performed by a sensitivity analysis, (3) To provide suggestions and guidance for long-term development planning in the study area. WLC and OWA methods were selected because the multi-criteria involved are reasonably combined, and the results are applicable and convincing (Malczewski 2004, Jiang et al. 2000, Romano 2015). Compared with the previous methods, this proposed method improved the applicability and accuracy of land use assessment and has advantages. For the purpose of this study, the principal criteria and sub-criteria concerning land use suitability for town development were four categories: topographic, environmental, socio-economic and historical sites criteria. The weight coefficients of each criteria were calculated by the analytic hierarchy process (AHP) method. Each criterion data was processed to present the value distribution in study area by GIS techniques. The distribution of degree of land use suitability was determined after applying the WLC and OWA methods. In the final stage of the problem, a sensitivity analysis and the overlay map indicated a satisfactory ecological fit between the two maps. Thus, the land use suitability method can support optimal decisions for town development planning for long-term sustainability in policy decisions.

2 Materials and Methods

2.1 Study area

Tangshan town was rated as the first batch of national touristic resorts in China in 2015. With the rapid urbanization, the environmental problems in Tangshan have become more and more prominent, such as man-made destruction of forest resources, reduction of water body, and landslide disasters. Land use suitability analysis is urgently required in order to keep up with the pace of town development, as well as to minimize adverse ecological impacts.

Tangshan new town is located near the center of Tangshan town, where it covers an area of 91.26 km^2 (Fig. 1). The study area is in the north subtropical monsoon humid areas. The average annual precipitation is 1106.5 mm, the annual average temperature is 15.4°C, and the annual extreme temperature is 39.7°C (max) and 13.1°C (min). Fig. 1 shows that Tangshan new town is surrounded by Shanghai-Chengdu Expressway, S122 Provincial Road to Shengtang Road. The topography of the research area is high at the center and low in the surrounding area. Tangshan mountain, with a height of about 294 meters, is located at the center of the study area. The existing construction land in the study area consists of residential land, commercial land, medical land and green land, covering an area of 18.11 km^2, accounting for 19.84% of the total area.

2.2 Multi-criteria relating to land use suitability for town development

Referring to the literature review (Ian 1995, William 2005, Li et al. 2017, Yan et al. 2018, Liu et al. 2018, Huang et al. 2019), an optimized multi-criteria evaluation system that included the principles of stability, independence, systematicness, and comprehensiveness was built, in accordance with the actual situation in the study area (Table 1).

2.3 Data sets

2.3.1 Data sources

The data sources used to evaluate each criterion were summarized in five approaches. Fig. 2 presented the maps for land use suitability criteria compiled by ArcGIS 10.2.

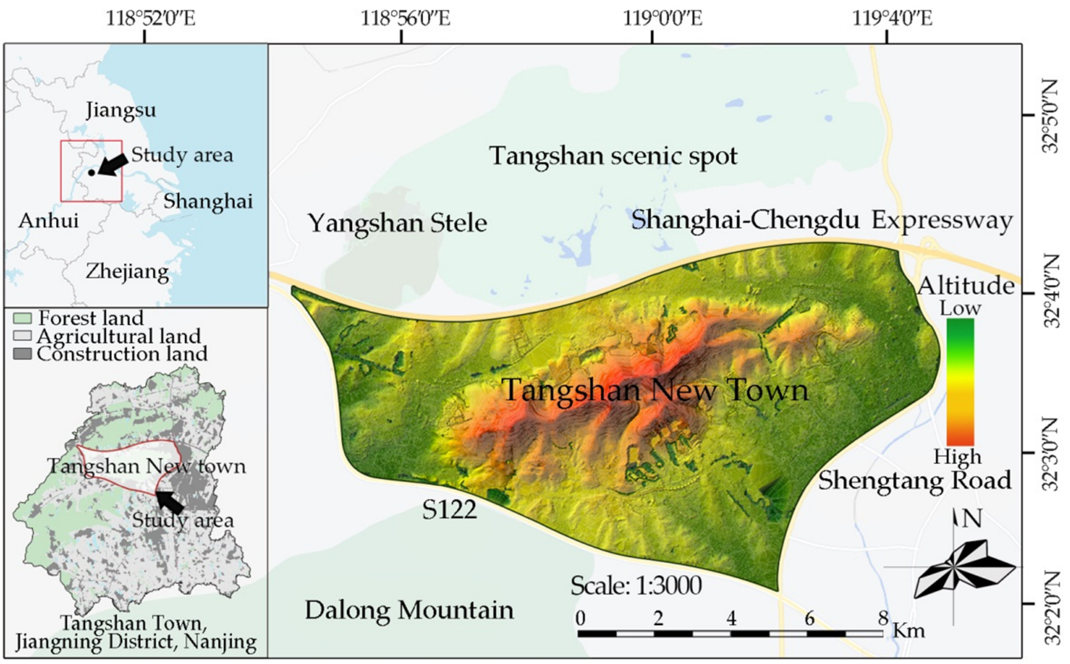


Fig. 1 Location, land use map and elevation map of Tangshan new town, Nanjing, China.

Table 1 Criteria of land use suitability evaluation for town development

Objective	Criteria	Sub-Criteria	Explanation
Land use suitability for town development	Topography	Terrain elevation (TE)	The terrain elevation of a location is its height above or below the Earth's sea level
		Slope (SL)	The steepness of the ground
		Exposure to geological hazard (EGH)	Landslides caused by natural factors or human activities
		Proximity to catchment area (PCA)	The area from which rain flows into a particular river or lake
	Environment	Proximity to surface water (river, lake and reservoir) (PSW)	Regional water resources, including ponds, lakes, rivers and reservoirs
		Proximity to hot spring (PHS)	A spring of naturally hot water, typically heated by subterranean heat
		Vegetation coverage (VC)	Reflects the growth of green vegetation in measuring regional ecological environment
	Socio-economics	Land use type (LUT)	The land classification according to the similarity and difference of land natural attributes and human production activities
		Population density (PD)	The number of people per unit land area
		Proximity to town built-up area (PTB)	The area where buildings and artificial structures have been densely built
		Proximity to road (PR)	The basic conditions of road traffic
		Proximity to the source of factory pollution (PSP)	Reflects the degree of factory pollution impact on the region
	Historical sites	Proximity to scenic resort and historic site (PSH)	Reflects the ecological and cultural values of scenic resorts and historic sites
		Proximity to ancient building (PAB)	The building was built before the republic of China, retaining historical and folk values

(1)The data of terrain elevation, slope and catchment areas in 2019 were derived from the digital elevation model (DEM) from geospatial data (source: http://www.gscloud.cn/).

(2) The data of geological hazards, surface water and vegetation coverage were taken from Landsat satellite remote sensing images in 2019 (source: http://www.gscloud.cn/) with field investigations.

(3) The data of land use types, hot springs and the sources of factory pollution were mapped using the existing land use map of Tangshan provided by the Land Resources Bureau of Nanjing.

(4) The data of population density was obtained from statistical census data from a digital administrative map provided by the Planning Bureau of Tangshan.

(5) The data of scenic resorts and historic sites, ancient villages and roads were extracted from the 1/200,000 hard copy maps obtained from the Planning Bureau of Nanjing.

2.3.2 Data standardized

Based on Food and Agricultural Organization (FAO) system (FAO 1976), a scoring and ranking system was adopted to standardize the criteria. Each criterion was divided into four suitability classes, i.e., highly suitable, moderately suitable, marginally suitable and not suitable (Table 2). Different from conventional standardization methods, such as linear transformation, the classification threshold values of the criteria and the standard scores for threshold given in Table 2 were derived by properly understanding of each factor's intrinsic properties and its impact on land suitability for the development of Tangshan town, and combining the literature, expert opinions, relevant regulations and standards of Nanjing. Here, the higher score of a criterion, the closer it was to a higher grade of land use suitability.

2.3.3 Weights

The analytic hierarchy process (AHP) method introduced by Saaty (1980) is one of the most widely used approaches to help people set priorities and make the best decision when determining the weights of multi-criteria. In initial formulation of AHP, Saaty (1990) proposed a four-step methodology comprising of modeling, valuation, inspection, and prioritization. At the first step, AHP method is applied to decompose complex problems into various constituent criteria with hierarchical structure, consisting of objectives,

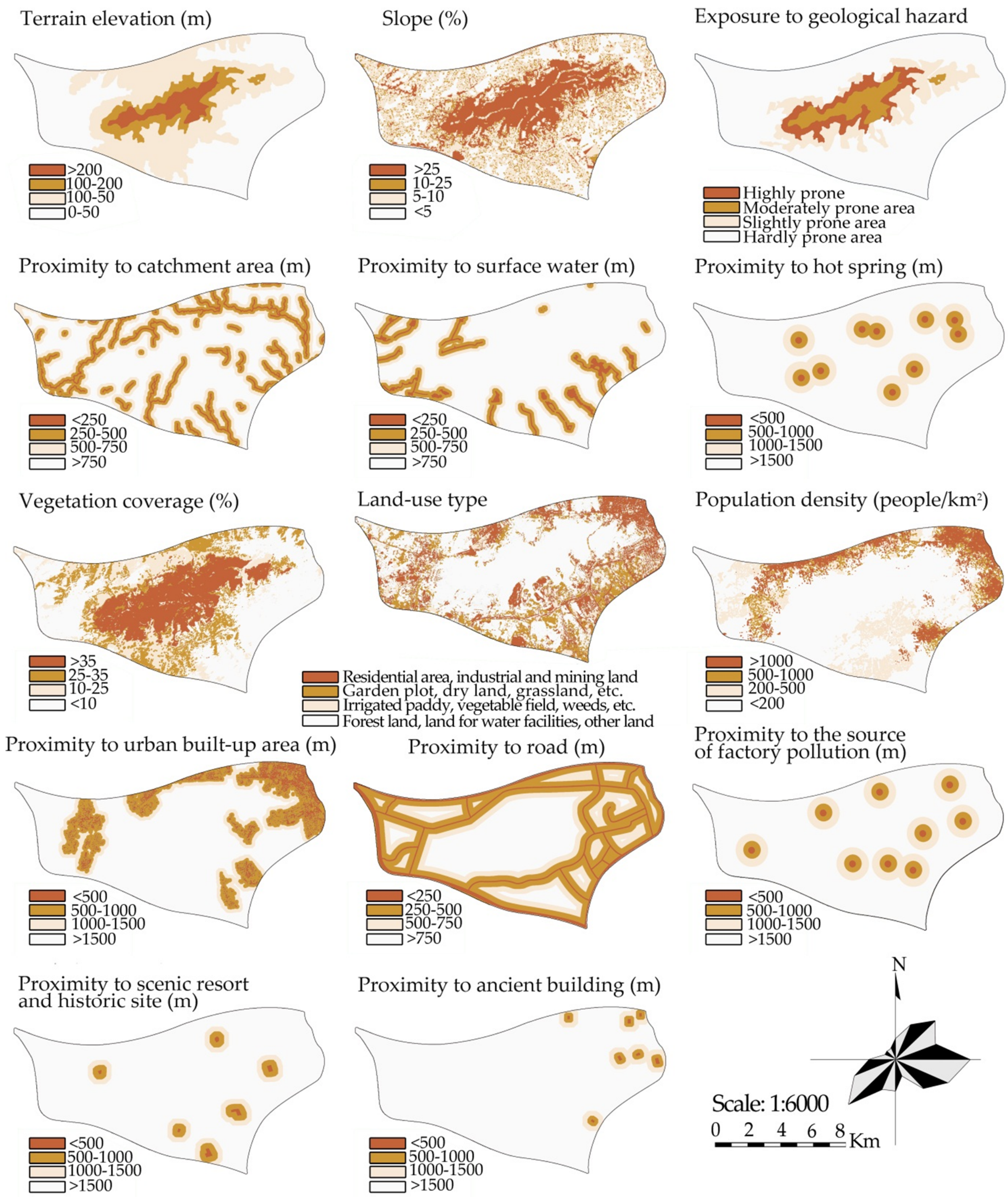


Fig. 2 Evaluation results of each land use suitability criterion of Tangshan new town in 2019.

criteria, sub-criteria, and alternatives. The objective of this study is land use suitability for town development, and the criteria and sub-criteria respectively consist of four and 14 criteria (Table 1). The second step involves comprosing the importance of pairs of criteria, pairs of sub-criteria (pairs of alternatives) (Table 3) and deriving the pairwise judgment matrix.

In this study, the relative importance of each criterion was assigned by using Delphi method to estimate the relative importance of the factors. The Delphi method is a pragmatic research method created by researchers at the RAND corporation in the 1950s for policy-making, organizational decision-making, and direct practices (Humphrey 1995). In this study, the Delphi

Table 2 Ranking and scoring system of criteria for land use suitability for town development

Rank	Not suitable	Marginally suitable	Moderately suitable	Highly suitable
Score	1	2	3	4
TE (m)[a]	>200	100-200	100-50	0-50
SL (%)[b]	>25	10-25	5-10	<5
EGH[c]	Highly prone area	Moderately prone area	Slightly prone area	Hardly prone area
PCA (m)[d]	<250	250-500	500-750	>750
PSW (m)[e]	<250	250-500	500-750	>750
PHS (m)[f]	<500	500-1000	1000-1500	>1500
VC (%)[g]	>35	25-35	10-25	<10
LUT[h]	Forest land, land for water facilities, other land	Irrigated paddy, vegetable field, weeds, bare land	Garden plot, grassland, other agricultural land	Residential area, industrial and mining land
PD (person/km^2)[i]	>1000	500-1000	200-500	<200
PTB (m)[j]	>1500	1000-1500	500-1000	<500
PR (m)[k]	>750	500-750	250-500	<250
PSP (m)[l]	<500	500-1000	1000-1500	>1500
PSH (m)[m]	>1500	1000-1500	500-1000	<500
PAB (m)[n]	>1500	1000-1500	500-1000	<500

Note: The full names of abbreviations are shown in Table 1.
[a] Score assignment was based on the characteristics of landform distribution of eastern China.
[b] Score assignment referred to the relationship between slope and urban development according to Liu (2018).
[c] Score assignment referred to the Master Plan of Nanjing (2011-2020).
[d, e] Score assignment was based on the Key Points of River and Lake Management of Nanjing in 2019 & the Regulations of Nanjing City on Water Environment Protection (2017 Amendment) & Master Plan.
[f] A hot spring had an exponentially decreasing impact on its surrounding environment with respect to increasing distance from hot spring, and the basic buffer value here was 500m using empirical classification.
[g] Score assignment referred to the research of vegetation coverage index (Yuan et al. 2019).
[h] Score assignment was based on the existing layout of Nanjing and the ecosystem services value of land cover according to Costanza et al. (1997).
[i] Score assignment referred to the agglomeration effect of population density using empirical classification.
[j] A town center had an exponentially decreasing impact on its hinterland with respect to increasing distance from town area, and the basic buffer value here was 500 m.
[k] Score assignment was based on the spatial agglomeration effects of roads and the basic buffer value was 250 m.
[l] Score assignment was based on the study of factory pollution according to Gilderbloom et al. (2020).
[m,n] Score assignment referred to the relationship between tourism and walkability according to Hall et al. (2019).

Table 3 Fundamental scale for pairwise comparison in analytic hierarchy process (AHP)

Value	Verbal scale	Explanation
1	Equal importance	Two activities contribute equally
3	Moderate importance of one over another	Experience and judgment slightly favor one activity over another
5	Strong importance	Experience and judgment strongly favor one activity over another
7	Very strong importance	An activity is favored very strongly over another
9	Extreme importance	An activity is favored by at least an order of magnitude
2-4-6-8	Intermediate value	A compromise between two judgments
1/9, 1/8, ... ,1/2	The reciprocal number expresses an opposite judgment	Experience and judgment “unfavor” one activity over another

method was used to reach a consensus of the relative importance of the factors among experts. The third step is to test the degree of consistency of the pairwise judgment matrix which is judged based on a consistency ratio (CR) index. If CR is equal to or less than 0.1, the consistency level is reasonably acceptable. Otherwise, the judgment matrix needs to be readjusted. In this study, the CR was 0.0422, indicating the judgment matrix consistent. At the fourth step, the final weight for each criterion is calculated by the normalized geometric mean of the rows in the judgment matrix. Table 4 listed the final criterion weight for land use suitability obtained by the AHP method and the judgment matrix of fourteen sub-criteria.

Table 4 Pairwise comparison matrix of criteria

Criteria	TE	SL	EGH	PCA	PSW	PHS	VC	LUT	PD	PTB	PR	PSP	PSH	PAB	Weights
TE	1	1	1	1	1/2	1/3	1	2	1	1	2	1	3	3	0.0816
SL	1	1	1	1	1/2	1/3	1	2	1	1	2	1	3	3	0.0816
EGH	1	1	1	1	1/2	1/3	2	2	2	2	2	1	1	1	0.0740
PCA	1	1	1	1	1/2	1/3	1	2	1	1	2	1	1	1	0.0631
PSW	2	2	2	2	1	1/2	2	2	1	2	2	1	1	1	0.0942
PHS	3	3	3	3	2	1	3	3	2	2	2	2	1	1	0.1405
VC	1	1	1/2	1	1/2	1/3	1	1	1	1	1	1	1/2	1/2	0.0501
LUT	1/2	1/2	1/2	1/2	1/2	1/3	1	1	1	1	1	1/2	1/2	1/2	0.0402
PD	1	1	1/2	1	1	1/2	1	1	1	1	1	1/2	1/2	1/2	0.0522
PTB	1	1	1/2	1	1/2	1/2	1	1	1	1	1	1/2	1/2	1/2	0.0489
PR	1/2	1/2	1/2	1/2	1/2	1/2	1	1	1	1	1	1/3	1/2	1/2	0.0409
PSP	1	1	1	1	1	1/2	1	2	2	2	3	1	1	1	0.0783
PSH	1/3	1/3	1	1	1	1	2	2	2	2	2	1	1	1	0.0771
PAB	1/3	1/3	1	1	1	1	2	2	2	2	2	1	1	1	0.0771

Note: The full names of abbreviations are shown in Table 1.
Largest eigenvalue = 14.8662. n = 14; Consistency index (CI) = (Largest eigenvalue - n)/(n - 1) = 0.0666. Random index = 1.58.
Consistency ratio (CR) = Consistency index/Random index = 0.0422.

2.4 Land use suitability mapping

2.4.1 GIS Analysis and Processing of Each Criterion Data

To achieve the research purposes, GIS analysis and processing of each criterion data are needed. Fig. 2 showed the evaluation results maps for fourteen land use suitability criteria, which presented the value distribution in our study area. All GIS layers were transformed into the same coordinate system and projection. The projection was Transverse Mercator, the central meridian was 120° E, and the Ellipsoid was WGS 1984. All the cell size of the criteria format layer was 30 m×30 m.

2.4.2 Weighted Linear Combination Approach

Weighted linear combination (WLC) (Chou 2013) was used as an aggregation method to generate town land use suitability results in this study. When using this method, the evaluation criteria are required to be standardized into a numerical range and then be combined by weighted average method. The formula of WLC is as follows:

$$WLC_j = \sum_{i=1}^{n} W_i \times X_i \qquad (1)$$

where WLC$_j$ represents the suitability score of the j_{th} pixel by WLC, W_i stands for the weight of criterion i, X_i is the standard score of criterion i, and n is the total number of criteria.

2.4.3 Ordered Weighted Averaging Approach

The Ordered Weighted Averaging (OWA) as a parameterized family of combination operators was proposed by Yager (1988). Herein, OWA is adopted and involves two sets of weights: criteria importance weights and order weights. The OWA formula is defined as follows:

$$OWA_j = \sum_{i=1}^{n} \left(\frac{W_i V_i}{\sum_{i=1}^{n} W_i V_i} \right) \times X_i \qquad (2)$$

where OWA_j stands for the suitability score of the j_{th} pixel by OWA, X_i is the standard score of criterion i, W_i is the weight of criterion i; V_i is the i_{th} element of a set of order weights V=(V_1, V_2,…,V_n). The set of W_i is the same as the set of criteria weight W used in the WLC. V_i is central to the OWA combination procedure. V_i controls the position of the aggregation operator on a continuum between the extremes of MIN and MAX, and incorporates a trade-off measure indicating the degree of compensation between criteria (Jiang et al. 2000). With different sets of order weights, OWA can generate a wide range of decision-making strategies, in terms of risks and tradeoffs (Malczewski et al. 2003).

A min-max disparity approach was used to assign order weights (Wang et al. 2005) as follows:

$$Minimize\left\{ \underset{j\in\{1,\ldots,n-1\}}{Max} \left| V_j - V_{j+1} \right| \right\}, \qquad (3)$$

$$\text{subject to } \alpha = \frac{1}{n-1}\sum_{j=1}^{n}(n-j)V_j, 0 \le \alpha \le 1,$$

$$\sum_{j=1}^{n} V_j = 1, 0 \le V_j \le 1,$$

in which α reflects the degree of ANDness and ORness. When α =1, ANDness=1 and ORness=0; α =0, then ANDness=0 and ORness=1. Besides,

$$Trade\ off = 1 - \sqrt{\frac{n\sum_{j=1}^{n}(W_j - \frac{1}{n})^2}{n-1}} \quad (4)$$

The value of α controls the position of the aggregation operator on a continuum between the extremes of MIN and MAX, as well as the degree of *trade off*.

Table 5 presented the order weights calculated from the criterion weights and the degree of ANDness and ORness (value of α, see above OWA approach). In this study, the choice of α =0.7 reflected a relatively strict standpoint that Tangshan new town was only included when most factors meet their thresholds.

2.4.4 Suitability Mapping

After determining the weights of criteria, criteria weights and criteria scores were appointed to the corresponding layers in the ArcGIS 10.2 environment, and combined with WLC and OWA approaches to overlaid raster maps of land use suitability criteria. Finally, weighted overlay mapping generated town land use suitability results. In order to enable decision makers to rank the results, the resultant map was classified into four levels as follows: not suitable, marginally suitable, moderately suitable, and highly suitable. The Jenks natural breaks tool in ArcGIS was used to classify the suitability levels, because once the number of levels was fixed, Jenks natural breaks method produced a result which ensured that data classified into different levels would have significant differences (Jenks 1967). A sensitivity analysis was performed to examine the robustness of the land use suitability results.

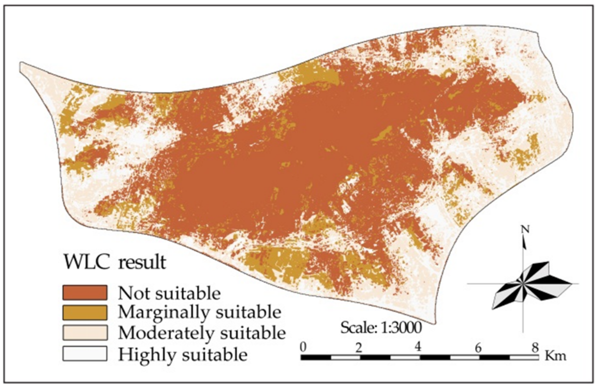


Fig. 3 Land use suitability map of Tangshan new town in 2019 generated by Weighted Linear Combination (WLC) approach.

3 Results

3.1 Map Resulting from WLC

Fig. 3 showed the land use suitability distribution for town development in Tangshan new town. It could be seen that the land use suitability level has decreased from the western, southern and eastern plains to the central mountain areas. The regions with highest suitability are located at the southern and eastern flat areas in the study area, whereas the regions close to the mountain forest areas, steep slope areas, water body, and hot springs, have lower suitability. Highly suitable areas for town development occupy 22.75 km² (24.93%) of the total area. Marginally suitable and not suitable areas cover 50.60 km² (55.45%) of the total area. The remaining 17.91 km² (19.62%) of the total area is moderately suitable for town development.

Fig. 4 showed an overlay analysis between the existing land use map and the WLC map, which provided information on the ratio of the existing development/non-development areas to the suitable/not suitable areas. Here, the development areas (with the total area of 32.65 km²) include special use, industrial and mining, transportation, and built-up areas (the others are classed as non-development). 2 5.08 km² (76.83%) of the development areas is overlaid by highly suitable areas (grouping highly suitable and moderately suitable as suitable, the others as not suitable). 17.86 km² (43.92%) of suitable areas (mostly being moderately suitable) remains non-development.

Table 5 The Ordered Weighted Averaging (OWA) approach order weights generated by the min-max disparity approach with α =0.7

Criteria	V_1	V_2	V_3	V_4	V_5	V_6	V_7
Weight	0.2039	0.1916	0.1385	0.1028	0.1000	0.0572	0.0543
Criteria	V_8	V_9	V_{10}	V_{11}	V_{12}	V_{13}	V_{14}
Weight	0.0531	0.0343	0.0343	0.0153	0.0147	0	0

Note: V_1 to V_{14} correspond to criteria with attribute values ranging from the highest to lowest.

3.2 Map Resulting from OWA

Fig. 5 showed the final land use suitability map for town development. Figs. 5 and 3 exhibited almost the same distributions of degree of suitability. Highly suitable areas cover 21.77 km² (23.85%) of the total area. Moderately suitable areas cover 18.36 km² (20.12%) of the total area. The remaining 51.13 km² (56.03%) of the total area is marginally suitable and not suitable areas.

3.3 Sensitivity Analysis

A sensitivity analysis was performed by altering the weight of each criterion that directly affects suitability. Fig. 6 showed the OWA suitability map's sensitivity to a 20% increase in the initial weight assigned to each criterion. When one criterion is increased by 20%, the other 13 are equally decreased by 1.43% to keep the sum of weights equal to 1. The high consistency indicates that the suitability map remained almost unchanged, and the percentage of different degree of suitability hardly changes with the increased weight (Fig. 6). Similar results are obtained in the WLC suitability map's sensitivity to a 20% increase of the initial weight and in both them maps' sensitivity to a 20% decrease of the initial weight. In general, it might be concluded that the land use suitability results are relatively robust and reliable.

3.4 Comparison of WLC and OWA Resultant Maps

Table 6 listed the results obtained from a comparison between the suitability maps generated using the WLC and OWA approaches. The degree of

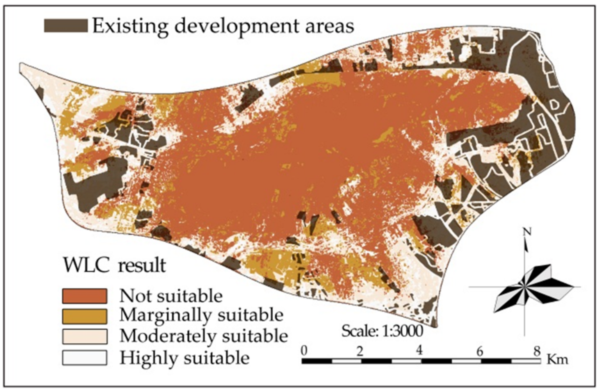


Fig. 4 Overlay analysis of Tangshan new town in 2019 between the existing land use map and the Weighted Linear Combination (WLC) map.

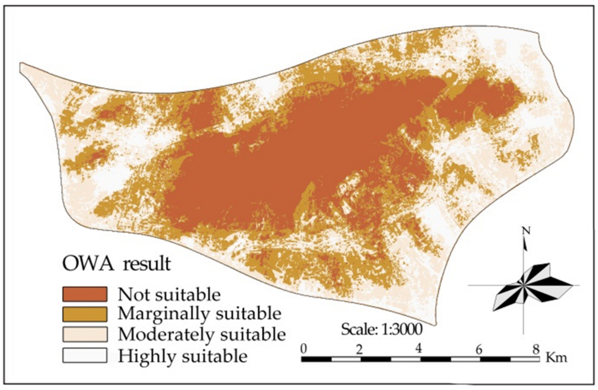
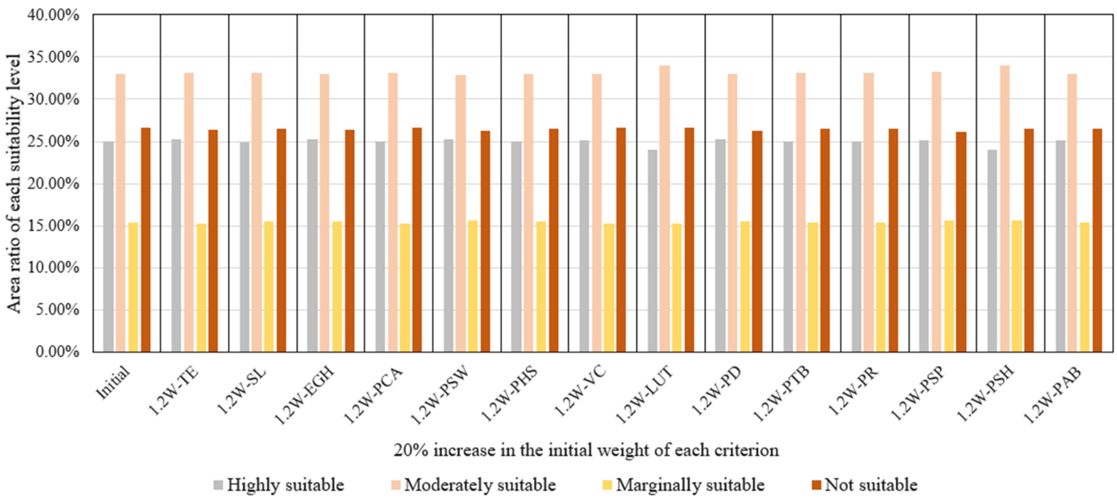


Fig. 5 Land use suitability map of Tangshan new town in 2019 generated by Ordered Weighted Averaging (OWA) approach.



Contingency coefficient: Initial: 1.00, $1.2W_{TE}$: 0.99, $1.2W_{SL}$: 0.98, $1.2W_{EGH}$: 0.98, $1.2W_{PCA}$: 0.99, $1.2W_{PSW}$: 0.98, $1.2W_{PHS}$: 0.97, $1.2W_{VC}$: 0.97. $1.2W_{LUT}$: 0.97, $1.2W_{PD}$: 1.00, $1.2W_{PTB}$: 1.00, $1.2W_{PR}$: 1.00, $1.2W_{PSP}$: 0.97, $1.2W_{PSH}$: 0.99, $1.2W_{PAB}$: 0.99.

Fig. 6 Sensitivity of suitability map of Tangshan new town in 2019 with 20% increase in the initial weight.

Table 6 Comparison of suitability maps between Weighted Linear Combination (WLC) and Ordered Weighted Averaging (OWA) approaches

WLC map (km²)	OWA map (km²)				
	Highly suitable	Moderately suitable	Marginally suitable	Not suitable	Total
Highly suitable	18.97	2.19	1.03	0.56	22.75
Moderately suitable	1.89	14.07	1.57	0.38	17.91
Marginally suitable	0.72	1.27	12.73	0.31	15.03
Not suitable	0.19	0.83	2.18	32.37	35.57
Total	21.77	18.36	17.51	33.62	91.26

Note: Overall agreement: 90.81%; kappa coefficient: 0.81.

agreement between the two maps was assessed by the statistics of overall agreement using spatial analysis and the contingency coefficients using kappa coefficient analysis. The overall agreement is the ratio of the area that have the same degree of suitability as that of the total sum. According to the research conclusions of Fleiss (1981), kappa coefficient less than 0.40 is poor, 0.40 to 0.75 is fair to good, and greater than 0.75 is excellent. In the comparison involving four suitability levels, the overall agreement of this study is as high as 90.81%, and the kappa coefficient is 0.81. In short, the WLC and OWA resulted in very similar spatial distributions of land use suitability.

4 Discussion

The land use suitability map and the priority zones planning in *the Master Plan of Nanjing (2011-2020)* were used to evaluate the ecological fit between their spatial patterns. Fig. 7 showed the OWA-derived suitability map, which overlies by four functional zones from priority zones planning. The priority functional zones were divided into four categories: the town development zone, the moderately town development zone, the ecological conservation function expansion zone and the ecological conservation zone. The first two zones are primarily related to development, and roughly correspond to areas in the suitability map classified as highly suitable and moderately suitable. Most of the planned ecological conservation function expansion zones are in accordance with areas classified as marginally suitable. The ecological conservation zone is consistent with areas that are not suitable, and most of the protected areas named in priority zones planning are situated, including mountain forests, surface water body, scenic resorts, different types of parks and hot springs. The overlay map once again indicates a satisfactory ecological fit between the sustainability map and priority zones planning.

4.1 Ecological Guidance for Land Development Planning in Tangshan New Town

According to the suitability map and the Priority Zones Planning in *the Master Plan of Nanjing (2011—2020)*, the following suggestions are recommended for the land spatial layout of the ecological conservation in Tangshan new town based on the principle of "Ecology-Priority and People-Oriented" (Fig. 8).

1. Strengthen the protection of forest land, water body, and biodiversity resources at the center of the study area.

In order to improve the ecological environment, forest land, water body and the protection projects of hot springs should be carried out strictly at the center of the study area. In order to strengthen the protection of the local wildlife and their habitats, the development of pollution projects must be controlled, and the agricultural land and bare land are encouraged to return to forests and grasslands.

2. Promote the construction of the landscape on both sides of the water and road corridors.

By constructing ecological corridors to improve

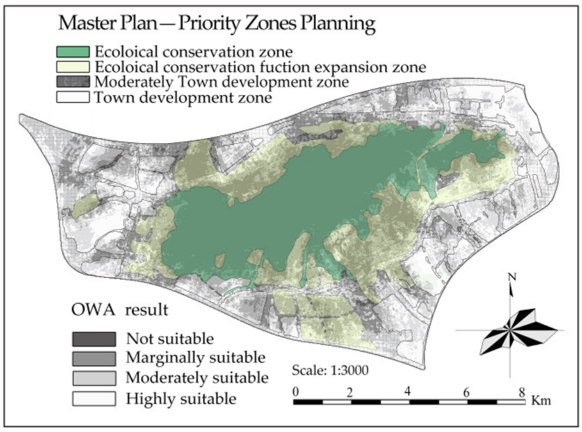


Fig. 7 Suitability map of Tangshan new town in 2019 generated by Ordered Weighted Averaging (OWA) overlaid with spatial patterns from the Master Plan of Nanjing (2011—2020).

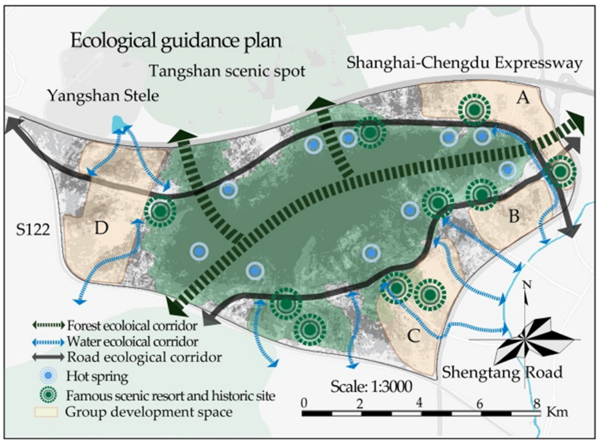


Fig. 8 Ecological guidance planning for Tangshan new town in 2019.

the ecological environment of forests, water body and roads, Tangshan new town will better connect the natural environment of the surrounding areas (Fig. 8). Water ecological corridors should be developed to form a "blue-green interweaved space" by strengthening the integration of water body and greening areas among the external water, farmland, and woodland resources. The geographical connectivity between Tangshan mountain and surrounding hilly regions is hoped to be rebuilt with road ecological corridors. Thus, an integrated ecological pattern will come into being.

3. Construct the multi-group spatial pattern with different local characteristics resources.

By integrating highly suitable land use space, four minor group development areas (Fig. 8. A, B, C, D) are planned in the research area. In order to tap resources with local characteristics, the minor areas organically connect various famous scenic resorts and historical sites, including historical parks, ancient buildings and historical cultural heritages (such as temple park, the buildings in period of Republic, human fossil sites, etc.). We hope that a vibrant hot-spring tourism town will be formed with important functions, like ecological maintenance, sightseeing tours, and recreation and entertainment.

4.2 Innovation and Limitations of the Study

This study introduced the land use suitability mapping for town development into Tangshan new town, which has prominent contradiction between the expansion of land use and ecological conservation. Although the accuracies of the models may depend on regional characteristics, the land use suitability mapping derived by using WLC or OWA approaches and GIS technology are reasonable method for land development planning to other areas, such as towns in southeastern China with similar hilly environment. Another thing we need to pay attention to is that when the town construction land continues to extend outward, the ecological guidance plan should be implemented strictly to construct a new-type town with harmonious coexistence between human and nature.

Due to the diversity of evaluation criteria as well as the complexity of town development, this research also has limitations in the evaluation criteria. In this paper, four attributes related to topographic, environmental, socio-economic and historical sites data are considered to evaluate the town land use suitability of the study area. However, it is believed that more environmental or social-economic data should be taken into account, particularly in investigating large-scale town land. The land use suitability is influenced by more than these attributes, such as heat and humidity that affect human comfort, and proximity to schools that are deemed important for a family with children. In the future, consideration of more criteria is expected to be able to generate more land use suitability reasonable evaluation results.

5 Conclusions

A land use suitability mapping approach for town development planning has been performed in Tangshan new town based on two multi-criteria evaluation methods: WLC and OWA. The evaluation criteria system is established by integrating topographic, environmental, socio-economic and historical sites data. The land use suitability is divided into four degrees, namely not suitable, marginally suitable, moderately suitable and highly suitable. About 25% of the total land area is found to be highly suitable while about 55% is marginally suitable and not suitable. A Sensitivity analysis indicates the suitability results of the two proposed methods are robust when subject to a uniform 20% change in the initial criteria weight. The suitability maps obtained using WLC and OWA methods exhibit very similar patterns of suitability degree. The overall agreement of 90.81% and the kappa coefficient of 0.81 indirectly validate the study approach. By overlaying the resultant map with previous map of *the Master Plan of Nanjing*, the overlay map once again indicates a satisfactory ecological fit between the two maps.

In short, the combined model of WLC, AHP and GIS is a convenient and reasonable method for land suitability analysis. The combination model of OWA, AHP and GIS provides a preferred method for government managing departments to provide practical decisions, since it introduces the order weighting criterion, which means that the results reflect not only the influence of criteria, but also the decision makers' attitudes. These two methods can potentially assist with the sustainable development of own renewal and land use planning, and result in the rapid, reliable, and fine-grained evaluation of land use suitability.

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Author Contributions

Yang Y and Tang XL conceived the idea and research design of this paper; Yang Y and Li ZH performed data analysis; Tang XL acquired the data; Yang Y wrote the paper.

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