Siting MSW landfills via the integration of DEMATEL-ANP and clustering algorithm in a fuzzy logic environment (Case Study: Lanzhou, China)

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Abstract: The siting of Municipal Solid Waste (MSW) landfills is a complex decision based process that involves multiple hydrogeological, morphological, environmental, climatic, and socio-economic criteria. In a fuzzy logic environment, DEMATEL and ANP methods were employed to comprehensively consider uncertainty, fuzziness of data and the subjective scoring and stability of results to enhance the spatial decision-making process. Primarily, 21 criteria were identified in five groups through the Delphi method at 30m resolution, criteria weights were determined via the integration of DEMATEL and ANP, and seven sets of membership functions were simulated to obtain the best fuzzy logic environment. Combining GIS spatial analysis and the three clustering algorithms (DBSCAN, HDBSCAN, and OPTICS), candidate sites that satisfied the landfill conditions were identified, and the spatial distribution characteristics and reachability were analyzed. These sites were subsequently ranked utilizing the MOORA, WASPAS, COPRAS, and TOPSIS methods to verify the reliability of the results by conducting sensitivity analysis. This paper focuses on a flexible and novel framework for the selection of MSW landfill sites for Lanzhou, which is a semi-
arid valley basin city in China. In contrast to common techniques, this model not only made the best recommendation scientifically and efficiently but could also provide accurate assessment data for decision makers in landfill construction and high-quality urban development.

**Keywords:**

DEMATEL-ANP  
fuzzy logic  
clustering  
municipal solid waste  
landfill  
site selection

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1. Introduction

Rapid urbanization and population growth have posed serious challenges to the sustainable development of cities, which have also led to environmental pollution and a dramatic increase in the generation of waste (Soltani et al., 2015). MSW is a critical issue with the potential to have severe negative impacts on the environment and public health (Khan et al., 2018). The disposal of immense volumes of Municipal Solid Waste (MSW) has become a matter of great concern for urban planners and environmental managers on a global scale. Over the last decade, global MSW generation has increased from 0.68 billion tonnes per year (0.64 kg of MSW per person per day) to 1.3 billion tonnes per year (1.2 kg per person per day), which is likely to reach 2.2 billion tonnes per year by 2025 (The World Bank, 2012).

Although China has experimented with waste classification and harmless treatment policies in Shanghai and other developed cities since 2018, landfilling remains the most essential and efficacious means for disposing of most MSW for the majority of economically underdeveloped areas (Zhang et al., 2019). It was revealed that improper landfills can have long lasting damaging impacts and cause potential harm to the surrounding ambient soil, groundwater, and atmosphere (Krcmar et al., 2018). Thus, the selection of suitable sites for landfilling is considered a complex task in Municipal Solid Waste Management (MSWM) (Chabuk et al., 2016). Lanzhou is a typical semi-arid valley basin city, where water resources are scarce, environmental pollution is serious, and the contrasts between anthropogenic activities and the land is extremely poignant (Li et al., 2020). Issues such as urban environment and land have become key issues to be urgently resolved during the construction of Lanzhou. Unlike humid coastal regions, the study area is characterized by a complex terrain and a significant fragile ecological environment. Therefore, it is critical to select
Siting MSW landfills often requires the engagement of multiple stakeholders encompassing government, municipalities, industries, experts, and the general public, where numerous criteria must be considered. Assuming no political or administrative boundaries as inputs, Karimi et al. (2020) proposed a data-driven GIS-based method that considers spatial, environmental, and economic constraints using study regions derived from nighttime light data. Based on the Analytic Hierarchy Process (AHP) and GIS technology Sener et al. (2010) combined social, environmental, and technical parameters to identify two candidate landfill sites for Konya, Turkey. Eskandari et al. (2012) conducted a similar study in Marvdasht, Iran, which drew on multi-criterion analysis and the GIS method and considering environmental, economic, and social factors. However, the aforementioned methods share a common weakness: Lack of support of relevant national standards, a low consideration for regional characteristics, and "NIMBY effects", which fail to form a perfect criterion system that is applicable to semi-arid regions. The criterion system is determined through the consideration of various factors such as environmental impacts (e.g., global warming, resource depletion, ecosystem damage), regional characteristics (e.g., waste generation rate, and social factors), associated economic costs and benefits, and resident acceptance.

Numerous Multi-Criteria Decision Analysis (MCDA) methods have been developed to support decision-making in MSWM, including AHP (Asefi et al.; Kamdar et al., 2019), Analytic Network Process (ANP) (Bahrani et al., 2016), Fuzzy logic (Chamchali and Ghazifard, 2019), Ordered Weighted Average (OWA (Gbanie et al., 2013), Weighted Linear Combination (Gorsevski et al., 2012), Fuzzy AHP(FAHP) (Hanine et al., 2016), and Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (FTOPSIS) (Beskese et al., 2015). As AHP is user-friendly, it transforms complex decision systems into simple hierarchies and paired systems, whereas GIS is a computer-based decision support system with the capacity to manage, analyze and display geospatial reference data (Khan et al., 2018). Therefore GIS-AHP has been proven to be a powerful tool for the evaluation of potential landfill sites (Mahmood et al., 2017). Gorsevski et al. (2012) who proposed a decision-
making strategy regulated by AHP, OWA, and GIS, took into account environmental and
economic criteria for waste disposal in various regions in Macedonia. Demesouka et al. (2013)
evaluated the suitability of potential MSW landfill sites in northeast Greece by applying GIS
combined with AHP and compromise programming methods. Spigolon et al. (2018) used an
AHP approach in a GIS environment for the siting of sanitary landfills and the optimization
of the transportation of municipal solid waste in São Paulo, Brazil. Kamdar et al. (2019) in
attempting to identify a suitable MSW site in Songkhla, Thailand, analyzed the data they
collected from online portals and governmental organizations, and then organized them by
morphological, environmental, and socioeconomic factors through a synthetic AHP-GIS
model.

However, AHP has several drawbacks including the fact that it is necessary to consider
the correlations between multiple criteria, and the establishment of a large number of paired
matrices to calculate weights may cause confusion. Further, the considerable reliance on
expert opinion leads to strong uncertainty and subjectivity in the data and results (Hossaini
et al., 2015). Consequently, it is essential to select an effective strategy to integrate the system
framework in a flexible and novel way to create an optimal decision-making plan. An
effective integrated model based on Decision-Making Trial And Evaluation Laboratory
(DEMATEL) and ANP was employed in environmental research and other fields (Feyz et al.,
2019). ANP views the mutual dependencies and feedback relationship between decision
elements (criteria, sub-criteria and optimal alternatives) as network structures, and effectively
determines the relative importance of evaluation criteria through the construction of a super
matrix (Rezaeisabzevar et al., 2020). There is no need to compare the evaluation criteria in
pairs, and the weight depends on the mutual effects between different criteria, which can
reduce the subjective impact of expert scoring to a certain extent. Moreover, there is some
research that focused on integrated MCDA-GIS methods under the fuzzy environment. Isalou
et al. (2013) studied the siting MSW landfills in Qom, Iran, using a linear membership
function and ANP in fuzzy logic. The results revealed that the use of fuzzy, rather than
Boolean theory, fully reflected the logical relationships between criterion attributes. However,
various evaluation criteria have different attributes, and there are uncertainties, and a mature
fuzzy environment has not yet been developed (Rahimi et al., 2020). Thus, as the literature suggests, the siting of MSW landfills requires further improvements in uncertainty, the fuzziness of data, methods and the stability of results to facilitate the evaluation process (Hariz et al., 2017).

This study proposed to integrate DEMATEL-ANP and GIS technology in the fuzzy logic environment to resolve the landfill site selection problem, while ensuring the certainty, fuzziness, and reliability of the optimal decision. Furthermore, previous studies have focused only on the process and results of the site selection, while neglecting the analysis of results. The density-based clustering algorithm can convert the suitability partition results into point elements for clustering, obtain candidate sites and analyze their spatial distribution characteristics and reachability (Eghtesadifard et al., 2020). The criteria are categorized as positive and negative, and the sites are the ranked according to the COmplex PRoportional ASsessment (COPRAS), the Weighted Aggregated Sum Product Assessment (WASPAS), the Multi-Objective Optimization method by Ratio Analysis (MOORA), and TOPSIS methods. These four methods have a high consistency with each other to and compensate for their probable shortcomings (Salabun et al., 2020). To the best of our knowledge, no study has been undertaken on the landfill site selection problem utilizing this flexible and novel comprehensive framework.

The overall objective of this study was not only to identify the most suitable site for MSW landfill by employing a decision support framework based on MCDM, but also to promote MSWM and sustainable urban development in response to regional characteristics, environmental management, and land-use planning of the study area. Specific objectives included: (a) Proposing a new flexible, practical, and comprehensive model to identify suitable landfills that minimize the negative impacts of MSW on the environment. (b) Working through the China National Standard (CNS) for site selection and construction, multiple stakeholders, literature reading, regional characteristics and the "NIMBY effect", identifying the criteria applicable to the site selection of semi-arid river valley basin-type urban landfills via a comprehensive consideration of hydrogeological, morphological,
environmental, climatic, and socioeconomic constraints. (c) In the fuzzy logic environment, the development of a network structure based on the mutual dependence between criteria rather than a pairwise comparison matrix, employing the clustering algorithm to determine a MSW landfill site that conformed to the CNS of environmental management and land use planning. Verifying the stability of the optimal decision plan according to ranking and sensitivity analysis.

This study is categorized into five main sections. In Section 1 the research background, research significance, goals, and scientific problems to be solved are introduced. In Section 2 the overview of the study area is described and the data sources are given. In Section 3 the proposed methodology including Delphi, DEMATEL-FANP, GIS, clustering algorithm, MOORA, WASPAS, COPRAS, and TOPSIS are described. Section 4 presents and discusses the results achieved by this study. Finally, Section 5 provides the concluding remarks and suggestions for further research.

2. Study area and data sources

2.1. Study area

Lanzhou (Fig.1) (103°40'E, 36°03'N) is located in the central part of Gansu Province, China. It is one of the typical river valley basin-type cities in semi-arid areas (Zhao et al., 2020). The terrain of the study area is high in the southwest and low in the northeast, with an average altitude of 1520m. The Yellow River flows from southwest to northeast across the entire territory and traverses the mountains, forming a beaded valley with alternate canyons and basins, which runs ~35 km from east to west and 2~8 km from north to south (Juang et al., 2019). The landforms are complex and diverse, with a staggered distribution of mountains, plateaus, plains, and river valleys. Due to the uplift of the Qinghai-Tibet Plateau since the new century, a temperate continental climate has been formed, with an average annual temperature of about 10.3°C and precipitation of about 327mm (He et al., 2019).

As of July 2020, the city has jurisdiction over five districts and three counties, with the approximate area of $1.31 \times 10^4$km$^2$ and population of over $4.13 \times 10^6$ people. According to
statistics from the Gansu Environmental Statistics Bulletin (GESB, 2009), 7.30×10^5 tons of domestic waste are generated annually in the four suburban districts of Lanzhou city, with 3.30×10^5 tons (45.7%) from Chengguan, 1.26×10^5 tons (17.3%) from Qilihe, 1.43×10^5 tons (19.6%) from Xigu, and 1.27×10^5 tons (17.4%) from Anning, which is increasing by from 5% to 8% per year. The annual output of domestic waste is ~1.05×10^6 tons, which generates 3,000 tons in the urban area every day; however, only 2100 tons can be landfilled, with a disposal rate of 70%. The remaining waste is spread across the surrounding areas of the city, which seriously restricts the development of Lanzhou. Fig. 2 illustrates the framework proposed in this study.

Fig. 1. Elevation of the study region. Lanzhou includes five districts (Honggu, Xigu, Anning, Qilihe, and Chengguan), and three counties (Yongdeng, Gaolan, and Yuzhong). Elevation data is from the USGS - SRTM dataset, which provides elevation data at a 30m resolution. The elevation of the study area ranged from 1399 to 3678 m.
Fig. 2. Flowchart of the proposed methodology, including four main steps: determine evaluation criteria, calculate weight, identify candidate sites, and validation.

2.2. Data sources

The amount of data used in this study was large and preprocessing was time consuming. According to the data format, it was divided into vector data (point, polyline, polygon) and raster data. Vector data focused on recording the properties of criterion, while raster data focused on representing the spatial distribution of the criterion. According to the data sources, the data were obtained from the open source geographic information sharing platforms,
online websites, and government agencies. The open source geographic information sharing
platform included the Resource and Environmental Science and Data Center, Chinese
Academy of Sciences (RESDC, 2015) and National Catalogue Service for Geographic
Information (NCSGI, 2015). Online websites included the official of MODIS (MODIS,
2018), USGS Earth Explorer (USGS, 2015), and Gaode Maps (GDM, 2019). Government
agencies included the Gansu Water Resources Department (GWRD, 2019), Gansu Bureau of
Geology and Mineral Hydrogeology engineering Geological Exploration Institute
(GBGMHEGEI, 2015), Gansu Earthquake Agency (GEA, 2015), and Portal website of
Gansu Forestry and Grass Bureau (GFGB, 2015). All of the criterion data sets used in this
study, as well as their formats and sources are described in Table A.1 in Appendix A.

3. Methods

3.1 Identification of evaluation criteria

The CNS have set strict standards for the evaluation criteria of landfill site selection and
construction. The specific CNS for reference include: "Standard for Pollution Control on the
Landfill Site of Domestic Waste" (GB16889-2008), "Technical Specifications for Sanitary
Landfill of Domestic Waste" (GB50869-2013), "Standard for Pollution on the Storage and
Disposal Site for General Industrial Solid Waste" (GB18599-2001), "Water Pollution
Prevention Law of the People's Republic of China", "Regulations of the People's Republic of
China on Nature Reserves", " Technical Regulations for Investigation of Land Use Status",
and " Urban and Rural Planning Law of the People’s Republic of China". All CNS are
available at the National Standard Full Text Open System (NSFTOS, 2017).

Delphi is an improved expert scoring method, which utilizes the questionnaire to
continuously iterate four times anonymously to investigate the scientific evaluation of multi-
domain experts on decision-making problems (Ahmed et al., 2020). The expert group
consists of 30 MSW experts, including academic researchers and professors in waste,
environmental, municipal management, land-use planning and geology, with an average of
12 years of practical or teaching experience in waste management. Combined with the CNS
and Delphi method, 21 sub-criteria (C1, C2, C3, ...., C21) were identified and were
categorized into five dimensions (B1, B2, B3, B4, and B5).

Hydrogeological aspects should be considered to avoid potential groundwater contamination in semi-arid valley basins caused by the leakage of landfill leachate, while ensuring the safety of construction and operation (Karakus et al., 2020). Morphological aspects were taken into account to reduce construction costs and increase stability during construction (Bahrani et al., 2016). Environmental aspects were taken into consideration to minimize the impacts on neighboring residents, and land/water resources (Ozkan et al., 2019). Climatic issues were reviewed to reduce potential threats and damage to the surrounding environment posed by various pollutants released from the landfill through leachate or waste gas (Lima et al., 2018). Socio-economic impacts were considered to prevent the landfill from adversely affecting surrounding ecological reserves and regional economic development (Asefi et al., 2020a). Further detailed information on the criteria selection is contained in Table B.1 in Appendix B. The interval from 0 to 1 was adopted for normalization, where the larger the value, the better the suitability (Fig. 2).
Fig. 3. Criteria included (a) groundwater depth, (b) groundwater quality, (c) groundwater richness, (d) distance from faults, (e) distance from earthquake points, (f) elevation, (g) slope, (h) soil type, (i) NDVI, (g) landform type, (k) distance from surface water, (l) distance from roads, (m) land use type, (n) distance from settlements, (o) precipitation, (p) temperature, (q) ecosystem service value, (r) population density, (s) GDP, (t) distance from airports, (u) distance from protected areas.

3.2 DEMATEL-FANP

This study aimed to integrate the DEMATEL-ANP method to establish a network structure to clarify the interdependent relationship between criteria and determine their relative weights. DEMATEL employs weighted directed figures and matrices to analyze causal relationships between criteria in complex systems, reflecting the overall impact of different criteria (Liu et al., 2020). It has the following advantages: (1) Distinguishing the attributes of criteria (positive and negative). (2) The prominence of the criteria can be determined. (3) The relationship between criteria can be quantified (direct and indirect influences). (4) A large number of samples are not required (Chang et al., 2011). It was reported that ANP was introduced to modify the AHP process, which finds the best possible solution for complex decision-making issues in the model of an ordered network structure (Afzali et al., 2014). Considering the mechanisms of dependency and feedback between the
criteria makes the decision-making model closer to the actual situation. To reduce the
uncertainty of data and expert ratings, ANP can utilize the causal relationship determined by
DEMATEL to calculate weights (Motlagh and Sayadi, 2015).

3.2.1. Construction of direct influence matrix

According to the expert opinion obtained by Delphi method, a numerical scale of 0-4 is
adopted to indicate the degree of direct influence between criteria. Where, "no influence" is
0, "low influence" is 1, "medium influence" is 2, "high influence" is 3, and "very high
influence" is 4. A pairwise comparison judgment matrix is constructed respectively. Experts
judged the criteria in order to derive a square matrix $A_E$ is expressed in Eq. 1. Subsequently, Eq. 1 indicates the average direct impact matrix, according to the equation, calculating the average value of the numerical scale for each matrix.

\[
A_E = \begin{bmatrix}
  a_{11}^E & a_{12}^E & \cdots & a_{1n}^E \\
  a_{21}^E & a_{22}^E & \cdots & a_{2n}^E \\
  \vdots & \vdots & \ddots & \vdots \\
  a_{n1}^E & a_{n2}^E & \cdots & a_{nn}^E
\end{bmatrix}
\]

\[
\bar{A} = \begin{bmatrix}
  \bar{a}_{11} & \bar{a}_{12} & \cdots & \bar{a}_{1n} \\
  \bar{a}_{21} & \bar{a}_{22} & \cdots & \bar{a}_{2n} \\
  \vdots & \vdots & \ddots & \vdots \\
  \bar{a}_{n1} & \bar{a}_{n2} & \cdots & \bar{a}_{nn}
\end{bmatrix}
\]  (1)

3.2.2. Normalization directly influences the matrix

To unify the numerical scale into a comparable range, Eqs. 2, 3 are employed to obtain
the normalized direct relation matrix, whose value is between 0 and 1.

\[
Z = \min \left[ \frac{1}{\max_j \left( \sum_{i=1}^{n} a_{ij} \right)}, \frac{1}{\max_j \left( \sum_{i=1}^{n} a_{ij} \right)} \right] \]  (2)

\[
A_n = Z \bar{A}  \]  (3)

3.2.3. Deriving the comprehensive influence matrix

The comprehensive influence matrix represents the superposition of direct and indirect
influences between criteria. $T^B$ (criterion) (Eq. 5) and $T^C$ (sub-criterion) (Eq. 6) are
calculated using Eq. 4, where $I$ is the identity matrix.
\[ T^C = \left[ \begin{array}{c} c_{ij} \end{array} \right]_{n \times n} = A_a (I - A_a)^{-1} \]  

(4)

\[ T^B = \begin{bmatrix} t^B_{11} & t^B_{12} & \cdots & t^B_{1m} \\ t^B_{21} & t^B_{22} & \cdots & t^B_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ t^B_{m1} & t^B_{m2} & \cdots & t^B_{mm} \end{bmatrix} \]  

(5)

\[ T^C = \begin{bmatrix} B_1 & C_{11} & C_{12} & \cdots & C_{1n} \\ B_2 & C_{21} & C_{22} & \cdots & C_{2n} \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ B_m & C_{m1} & C_{m2} & \cdots & C_{mn} \end{bmatrix} \]  

(6)

3.2.4 Computing influence and being influence of the matrix

Based on the comprehensive influence matrix, the row vectors are summed to obtain the influence of the criterion \( i \) on other criteria (influence). The column vectors are summed to obtain the influence of the other criteria on the criterion \( i \) (being influence). Further, the values of \( R^B \) and \( C^B \) denote the influence and being influence of the criteria, whereas the values of \( R^C \) and \( C^C \) denote the influence and being influence of the sub-criteria (Eqs. 7, 8).

\[ R^B = \left[ r^B_{ij} \right]_{n \times n} = \sum_{j=1}^{n} t^B_{ij} \]  

(7)

\[ C^B = \left[ c^B_{ij} \right]_{n \times n} = \sum_{j=1}^{n} t^B_{ji} \]  

\[ R^C = \left[ r^C_{ij} \right]_{n \times n} = \sum_{j=1}^{n} t^C_{ij} \]  

(8)

3.2.5. Establishing the network structure

ANP establishes the network structure with assistance from the comprehensive influence matrix and constructs the super matrix to allocate the weight for the criteria. To distinguish the difference between the criteria, Eq. 9 is employed to calculate the centrality \( M \) and causation \( N \). The network structure is based on coordinate values \( (M, N) \) to express the interdependence and feedback influences between criteria, and its comprehensive threshold is set as the average value of the matrix and medium numerical scale.
\[ M_i = R_i + C_i \quad N_i = R_i - C_i \]  

(9)

3.2.6. Normalization of comprehensive influence matrix

Based on the comprehensive influence matrix, the criterion normalized comprehensive influence matrix \( \mathbf{T}^B = [t_{ij}]_{m \times n} \) (Eq. 10, 11) was calculated by the row vector of criterion \( i \) divided by the sum of the row vector of its corresponding row. The sum of the numerical scales for each row vector is 1: \( \sum_{j=1}^{n} t_{ij}^B = 1 \). Similarly, the normalized comprehensive influence matrix of the sub-criterion is obtained by the same method (Eq. 12).

\[
\mathbf{T}^B = \begin{bmatrix} t_{11}^B & t_{12}^B & \cdots & t_{1m}^B \\ t_{21}^B & t_{22}^B & \cdots & t_{2m}^B \\ \vdots & \vdots & \ddots & \vdots \\ t_{m1}^B & t_{m2}^B & \cdots & t_{mm}^B \end{bmatrix} \rightarrow b_i = \sum_{j=1}^{n} t_{ij}^B \\
\mathbf{T}_a^B = \begin{bmatrix} t_{11}^B & t_{12}^B & \cdots & t_{1m}^B \\ \vdots & \vdots & \ddots & \vdots \\ t_{m1}^B & t_{m2}^B & \cdots & t_{mm}^B \end{bmatrix} = \begin{bmatrix} t_{a_{11}} & t_{a_{12}} & \cdots & t_{a_{1n}} \\ \vdots & \vdots & \ddots & \vdots \\ t_{a_{m1}} & t_{a_{m2}} & \cdots & t_{a_{mn}} \end{bmatrix}
\]

(10)

(11)

\[
\mathbf{T}^C = \begin{bmatrix} T_{a_{11}}^C & T_{a_{12}}^C & \cdots & T_{a_{1m}}^C \\ \vdots & \vdots & \ddots & \vdots \\ T_{a_{n1}}^C & T_{a_{n2}}^C & \cdots & T_{a_{nm}}^C \end{bmatrix}
\]

(12)

3.2.7. Construct and solve the limit super matrix
The weighted super matrix $W_C$ (Eq. 13) is expressed by multiplying the normalized comprehensive influence matrix of the criterion of transpose and the sub-criterion of transpose. The weighted super matrix is limit until it converges to calculate the final weight vector (Eq. 14).

\[
W_C = (T^B \alpha)^T \times (T^C \alpha)^T = \begin{bmatrix}
t^B_{\alpha_11} \times t^C_{\alpha_11} & t^B_{\alpha_21} \times t^C_{\alpha_21} & \cdots & t^B_{\alpha_{m_1}} \times t^C_{\alpha_{m_1}} \\
t^B_{\alpha_12} \times t^C_{\alpha_12} & t^B_{\alpha_22} \times t^C_{\alpha_22} & \cdots & t^B_{\alpha_{m_2}} \times t^C_{\alpha_{m_2}} \\
\vdots & \vdots & \ddots & \vdots \\
t^B_{\alpha_1w} \times t^C_{\alpha_1w} & t^B_{\alpha_2w} \times t^C_{\alpha_2w} & \cdots & t^B_{\alpha_{m_w}} \times t^C_{\alpha_{m_w}}
\end{bmatrix}
\]

\[
\lim_{k \to \infty} (W_C)^k = (13)
\]

\[
\alpha
\]

\[
\text{Table 1}
\]

M(R+C), N(R-C) and weights for criterion and sub-criterion.

| Criterion          | M(R+C)     | N(R-C)     | Sub-criterion       | M(R+C)     | N(R-C)     | Weight |
|--------------------|------------|------------|---------------------|------------|------------|--------|
| Hydrogeological B₁ | 1.85113269 | -0.81553398| Groundwater depth C₁| 6.10592753 | 0.37294637 | 0.0710 |
| Groundwater quality C₂ | 3.44870236 | 0.68060181 | | 0.0416 |
| Groundwater richness C₃ | 5.57912930 | 0.48638054 | | 0.0642 |
| Distance from faults C₄ | 4.92364358 | 0.52814645 | | 0.0582 |
| Distance from earthquake points C₅ | 3.38080534 | 0.38108087 | | 0.0398 |
| Morphological B₂ | 1.75674218 | -0.13214671| Elevation C₆ | 4.55369593 | 0.32910353 | 0.0530 |
| Slope C₇ | 5.47245800 | 0.11232891 | | 0.0616 |
| Soil type C₈ | 4.25869870 | 0.17304975 | | 0.0432 |
| NDVI C₉ | 4.59700315 | -0.90900132 | | 0.0380 |
| Landform type C₁₀ | 4.39911408 | -0.73593001 | | 0.0380 |
The mapping and analysis of criteria attributes based on fuzzy logic, S-shape, Triangular shape, and Gamma shape are commonly employed fuzzy membership functions to determine fuzzy information in fuzzy logic (Table 2) (Barakat et al., 2017). The effects of the seven applied scenarios were investigated, aiming to obtain the most suitable scenario to improve the accuracy of the results and optimize the uncertainty of the evaluation criteria.

Scenario 1: All criteria employ the nonlinear fuzzy membership function (S-shape) to calculate the fuzzy membership.

Scenario 2: All criteria employ the linear fuzzy membership function (Triangular shape) to calculate the fuzzy membership.
Scenario 3: All criteria employ the linear fuzzy membership function (Gamma shape) to calculate the fuzzy membership.

Scenario 4: Criteria employ S and Triangular shapes to calculate the fuzzy membership.

Scenario 5: Criteria employ S and Gamma shapes to calculate the fuzzy membership.

Scenario 6: Criteria employ Triangular and Gamma shapes to calculate the fuzzy membership.

Scenario 7: Criteria employ S, Triangular, and Gamma shapes to calculate the fuzzy membership.

Table 2

Fuzzy membership function.

| Fuzzy Membership Function | Figure | Formula |
|---------------------------|--------|---------|
| S-shape                   | S-shape| $\mu_i = \begin{cases} 0 & x_i \leq a \\ 2\frac{x_i-a}{b-a} & a < x_i < b \\ 1 & x_i \geq b \end{cases}$ |
| (increasing)              |        |         |
| S-shape                   | S-shape| $\mu_i = \begin{cases} 0 & x_i \leq a \\ 2\frac{x_i-a}{m-a} & a < x_i \leq m \\ 2\frac{x_i-b}{b-m} & m < x_i < b \\ 0 & x_i \geq b \end{cases}$ |
| (general)                 |        |         |
| S-shape                   | S-shape| $\mu_i = \begin{cases} 1 & x_i \leq a \\ 2\frac{x_i-b}{b-a} & a < x_i < b \\ 0 & x_i \geq b \end{cases}$ |
| (decreasing)              |        |         |
3.3. GIS modeling

3.3.1 Spatial analysis

On the basis of the unified projection coordinate system, all data are converted to raster format and resampled for 30 m. Modeling is carried out with the help of spatial analysis tools in ArcGIS software to obtain reasonable results of landfill site selection. Buffer zones are established for faults, earthquake points, surface water, settlements, roads, protected areas, and airports in accordance with the CNS for waste landfill sites, and the regional characteristics of the valley basins in the semi-arid area of Lanzhou. The weights and fuzzy layers calculated by DEMATEL-FANP are integrated, and the weighted overlay of layers and smooth the neighborhood are implemented to obtain the landfill site selection results.

3.3.2. Cluster analysis

Compared with the K-Means method, the density-based clustering analysis does not require prior knowledge of the number of clusters to be formed, the shape of the clusters is not limited, and noise points can be identified.
I. Density-Based Spatial Clustering of Applications with Noise (DBSCAN)

The input parameters are the neighborhood radius ($\varepsilon$) and the minimum number of entities (MinPts). The data set is divide into core, boundary and noise points. A random point is selected from the data set as the seed for traversal. When the density of any two points is reachable or direct, it is classified into the same cluster, and the number of entities in the same cluster must be greater than MinPts; when it is less, they are classified as noise points (Gui et al., 2020).

II. Hierarchical Density-Based Spatial Clustering of Applications with Noise (HDBSCAN)

The input parameter is MinPts, $\varepsilon$ changes with the point density change, automatic clustering can be implemented without parameter adjustment. On the basis of DBSCAN and in combination with the hierarchical clustering algorithm, the concept of "Mutual Reachability Distance" was introduced (Hu et al., 2020).

$$MRD_{\varepsilon(A,B)} = \max\{Core_k(A), Core_k(B), d(A,B)\}$$ \hspace{1cm} (15)

Where, A, B are two core points; $Core_k(A)$ is the distance between A and the K-th adjacent point; $Core_k(B)$ is the distance between B and the K-th adjacent point; $d(A,B)$ is the Euclidean distance between A and B.

III. Ordering Points to Identify the Clustering Structure (OPTICS)

The input parameters were $\varepsilon$, MinPts, and sensitivity. The value of clustering sensitivity is 0-100. The higher the sensitivity, the smaller the clustering interval is. And introduced the "accessible distance" (Breunig et al., 2000).

$$RD_{(P,Q)} = \max\{Core(P), d(P,Q)\}$$ \hspace{1cm} (16)

Where, P, Q are the two core points, the core distance of P, and the Euclidean distance between P and Q.
3.4. Ranking solution

3.4.1 WASPAS

Step 1 Construct a decision matrix $X = [x_{ij}]$, where $x_{ij}$ is the response of alternative item $i$ to criterion $j$.

Step 2 Normalize the decision matrix based on the maximum and minimum method (Eq. 17) (Salabun et al., 2020).

\[ r_{ij}^+ = \frac{x_{ij}}{\max_j(x_{ij})} \quad \text{for positive criteria} \quad r_{ij}^- = \frac{\min_j(x_{ij})}{x_{ij}} \quad \text{for negative criteria} \quad (17) \]

Step 3 Weight normalized decision matrix (Eq. 18), $w_j$ is the weight of criterion $j$.

Step 4 Calculate the relative importance of alternatives by utilizing weighted sum model (WSM) and weighted product model (WPM) (Zavadskas et al., 2012), where $m$ is the number of alternatives.

\[ S_{WSM} = \sum_{j=1}^{n} w_j r_{ij} \quad S_{WPM} = \prod_{j=1}^{n} (r_{ij})^{w_j} \quad (18) \]

Step 5 Calculate the scores of each alternative according to Eq. 19, and arrange them in descending order.

\[ Q_i = \lambda S_{WSM} + (1-\lambda) S_{WPM} \quad \lambda \in [0,1] \quad (19) \]

3.4.2 MOORA

Step 1 Construct a decision matrix $X = [x_{ij}]$, where $x_{ij}$ is the response of alternative item $i$ to criterion $j$.

Step 2 Normalize the decision matrix based on the vector method (Eq. 20), where $m$ is the number of alternatives.

\[ r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{j=1}^{m} x_{ij}^2}} \quad (20) \]
Step 3 Weight normalized decision matrix (Eq. 21), \( w \) is the weight of criterion \( j \).

\[ V_{ij} = w_j r_{ij} \]  \hspace{1cm} (21)

Step 4 Calculate the relative importance of alternatives by utilizing the ratio of the system (Eq. 22) (Brauers and Zavadskas, 2006), where \( n \) is the number of criteria.

\[ S_i^+ = \sum_{j=1}^{g} V_{ij} \text{ for positive criteria} \quad S_i^- = \sum_{j=g+1}^{n} V_{ij} \text{ for negative criteria} \]  \hspace{1cm} (22)

Step 5 Calculate the scores of each alternative according to Eq. 23, and arrange them in descending order.

\[ Q_i = \sum_{j=1}^{g} V_{ij} - \sum_{j=g+1}^{n} V_{ij} \]  \hspace{1cm} (23)

3.4.3 COPRAS

Step 1 Construct a decision matrix \( X = [x_{ij}] \), where \( x_{ij} \) is the response of alternative item \( i \) to criterion \( j \).

Step 2 Normalize the decision matrix based on the summation method (Eq. 24), where \( m \) is the number of alternatives.

\[ r_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \]  \hspace{1cm} (24)

Step 3 Weight normalized decision matrix (Eq. 25), \( w \) is the weight of criterion \( j \).

\[ V_{ij} = w_j r_{ij} \]  \hspace{1cm} (25)

Step 4 Calculate the relative importance of alternatives by utilizing the complex scale evaluation index (Eq. 26) (Pamucar et al., 2018), where \( n \) is the number of criteria.

\[ S_i^+ = \sum_{j=1}^{g} V_{ij} \text{ for positive criteria} \quad S_i^- = \sum_{j=g+1}^{n} V_{ij} \text{ for negative criteria} \]  \hspace{1cm} (26)

Step 5 Calculate the scores of each alternative according to Eq. 27, and arrange them in descending order. The higher the score, the higher the priority.
\[ Q_i = S_i^+ + \frac{\sum_{j=1}^{m} S_j^-}{S_i^- \sum_{j=1}^{m} \frac{1}{S_j^-}} \quad \quad U_i = \frac{Q_i}{Q_{\text{max}}} \times 100 \]  

(27)

3.4.4 TOPSIS

Step 1 Construct a decision matrix \( X = [x_{ij}] \), where \( x_{ij} \) is the response of alternative item \( i \) to criterion \( j \).

Step 2 Normalize the decision matrix based on the minimum-maximum method (Eq. 28), where \( m \) is the number of alternatives.

\[ r_{ij}^+ = \frac{x_{ij} - \min_j(x_{ij})}{\max_j(x_{ij}) - \min_j(x_{ij})} \text{ for positive criteria} \]

(28)

\[ r_{ij}^- = \frac{\max_j(x_{ij}) - x_{ij}}{\max_j(x_{ij}) - \min_j(x_{ij})} \text{ for negative criteria} \]

Step 3 Weight normalized decision matrix (Eq. 29), \( w \) is the weight of criterion \( j \).

\[ V_{ij} = w_j r_{ij} \quad V_j^+ = \{\max_j(V_{ij})\} \quad V_j^- = \{\min_j(V_{ij})\} \]

(29)

Step 4 Calculate the relative importance of alternatives by utilizing the distance index (Eq. 30) (Rashid et al., 2014), where \( n \) is the number of criteria.

\[ S_i^+ = \sqrt{\sum_{j=1}^{n} (V_{ij} - V_j^+)^2} \quad S_i^- = \sqrt{\sum_{j=1}^{n} (V_{ij} - V_j^-)^2} \]  

(30)

Step 5 Calculate the scores of each alternative according to Eq. 31, and arrange them in descending order.

\[ Q_i = \frac{S_i^-}{S_i^+ + S_i^-} \]  

(31)

4. Results and discussion

4.1 Determining the weight
The comprehensive influence matrix of the criterion and sub-criterion (Tables B.2, B.3 in Appendix B) are derived by calculating the mean value of the direct and the normalized direct impact matrices. Ultimately, a statistical analysis was performed on the criteria (Table 1). It can be seen from the table that in the criteria, the environmental criterion shows the highest M value (2.5949) and the highest N value (0.7060). The climatic criterion M value (1.1510) is the lowest, and the hydrogeological criterion N value (-0.8155) is the lowest. In the sub-criteria, soil type, landform type, land use type, distance from settlements, population density, GDP, and distance from airports are the being affected criteria, while the others are affected criteria. The M value (6.5923) of distance from surface water was the highest, and the N value (0.6806) of groundwater quality was the highest. The M value (1.2955) of temperature was the lowest, and the N value (-0.9090) of NDVI was the lowest. Furthermore, the weight of temperature (0.0142) and precipitation (0.0214) was lowest, due to the dry climate, low annual precipitation, and lower leachate pollution generated by landfills in the semi-arid region of Northwest China, which is significantly different from that in humid regions. The weights of land use type (0.0531) and ecological service value (0.0641) were relatively high, which was due to the scarcity of land in river valleys and basins. In particular, urban expansion leads to the development and utilization of farmland, forestland, water, and other ecological land that is close to central urban areas. Lanzhou is one of the cities with the most serious geological disasters in China. It is located in the Qilian Mountain earthquake belt, where the abundance of historical landslides, debris flows, and earthquakes should not be underestimated. Considering the geological structure and development of the study area, the weights of faults and earthquake points are 0.0582 and 0.0398, respectively. Water areas, settlements, and protected areas are constraints that are strictly stipulated by the CNS; thus, the relative weight value is also high.

4.2 Identifying the landfill site

The suitability map is generated through overlaying the fuzzy normalized layer of all criteria and assigning weights for each criterion. Subsequently, the results are divided into five categories: "most suitable, more suitable, suitable, less suitable, and unsuitable". Its area
and proportions were "6288 km² (0.48), 3275 km² (0.25), 2358 km² (0.18), 917 km² (0.07), and 262 km² (0.02)" respectively. Simultaneously, non-constructible areas are eliminated according to the CNS, including mainly rivers, protected areas, central urban areas, airports, and so on.

It was found that there were slight differences by comparing the application results of the six scenarios of fuzzy logic with the initial scenario. The most suitable area ratios of scenarios 1-7 were 0.05, 0.06, 0.06, 0.04, 0.04, 0.05, and 0.02, respectively. In addition, Spearman's correlation coefficient values of scenario 1 and the others were compared, which confirmed the similarities between them. Scenarios 2 and 3 had the highest degree of variation in area ratio, which is why they reduced the correlation coefficient (0.94). The coefficient scores of scenarios 4 and 7 were 1, where the results graphically highlighted that the expression of the criterion fuzziness was not limited to linear functions. The reliability of the results could be improved by establishing corresponding membership functions according to different criterion attributes to indicate the logical relations and fuzziness.

The "most suitable" category in the results of scenario 7 was selected, and 140103 data points were extracted for density-based cluster analysis to intuitively display the spatial distribution characteristics and reachability of candidate sites (Figs. C.1, C.2, Appendix C). The DBSCAN method has the fastest calculation speed, where following many experiments and comparisons, it selects the ε of 1600 m and the MinPts of 1000 for cluster analysis, and obtains 15 clusters, and 1 is the noise point. Overall, the U-3 candidate sites located ~1700 m southeast of Liangjiawan in the Xigu District had the smallest density and area, and were closest to the Yellow River among all candidate sites; thus, they were classified as noise points. As a method to merge as many entities as possible, HDBSCAN is data-driven and can directly reflect the aggregation of the data itself. 1000 MinPts were taken to obtain 15 clusters, and 1 was the noise point. As can be seen from the results, a small part of the U-3 candidate sites located ~1700 m southeast of Liangjiawan in the Xigu District were divided into noise points, while the rest were grouped together with S-11, and the value of probability 1 was the highest in the membership probability distribution presented. OPTICS overcomes the
shortcoming that low-density clusters within a neighborhood radius contains high-density clusters. Meanwhile, it is not completely data-driven and has obvious advantages for the analysis of spatial distribution characteristics. The ε was set to 1600 m, MinPts to 1000, and cluster sensitivity to 10, after which a total of 13 classes of clusters were obtained, and the 1 was the noise point, including U-1, U-2, and U-3. Lower vertical coordinates in the Reachability Chart translate to lower reach distances. The blue area in Fig. D2 indicates a higher clustering density and better suitability due to the lowest ordinate. The corresponding candidate site (S-6) is located on the east side of Ruijiawan, Lanzhou. Eleven candidate sites were identified by integrating the three clustering algorithms (Fig. 4). It can be seen that the sites are primarily distributed across Yongdeng, Gaolan, and Yuzhong Counties, with a lower distribution in central urban areas and smaller areas. The major reasons are that counties contain more unused land, are close to central urban areas, and transportation is convenient. Conversely, in central urban areas there are mass settlements, land is limited, and water resources are scarce.

The daily MSW capacities of the candidate sites were calculated according to the “Construction Standard of MSW Landfill Disposal Engineering Project” (Tables D.1, D.2, Appendix D). There were four candidate landfills (S-3, S-5, S-7, and S-8) in Yongdeng, three candidate sites (S-4, S-5, and S-6) in Gaolan, and one candidate site (S-2) in Yuzhong, each of which could accommodate more than 1200 tons/day of MSW. One of the most suitable candidate landfill sites in Honggu (S-9) had a capacity of 500 to 1200 tons/day of MSW. The candidate sites in Xigu and Anning were S-10 and S-11, both of which could accommodate 200 to 500 tons/day of MSW. Qilihe and Chengguan had no optimal sites. A comparison of the population densities in the study area, the official forecast of garbage growth, and the capacity of the candidate sites indicated that the landfill capacity would not reach saturation for at least a decade.
Fig. 4. Site selection of MSW landfills in Lanzhou. The red areas were the most suitable landfill sites, with a total of 11 candidate sites selected.

4.3. Validation

The 11 candidate sites identified by cluster analysis were satisfactory from the perspective of hydrogeological, morphological, environmental, climatic, and socio-economic factors, as they were all based on criteria analysis. However, to ensure that the candidate sites conformed to the CNS and the urban planning measures of the study area, it was necessary to evaluate them relatively. We conducted field visits and selected four methods: WASPAS, MOORA, COPRAS, and TOPSIS to determine the final ranking of the candidate sites by according to expert opinions and regional characteristics. As can be seen from Table 3, the ranking results of WASPAS and COPRAS were the same, as were MOORA and TOPSIS, whereas the four methods were slightly different for S-5, S-7, S-8, and S-10. The correlation coefficient of WASPAS-COPRAS and MOORA-TOPSIS was 1, and for WASPAS-MOORA, WASPAS-TOPSIS, COPRAS-MOORA, and COPRAS-TOPSIS was 0.94. As such, it was confirmed that there was a high degree of consistency between the ranking results of the
candidate sites, with S-1 being the most suitable.

In this study, sensitivity analysis charts were established for 13 scenarios with different weights to reflect the influences of changes in criterion weights on the final results and ranking stability (Fig. E.2 in Appendix E). Spearman's correlation coefficient was employed to analyze four ranking methods in the scenario simulation with different weights (Table E.1 in Appendix E). As can be seen from the Figure, the ranking of scenarios 4, 6, and 7 changed among the four ranking methods, which was due to their low correlation coefficients between and the original weighting scenario 1. The ranking order of the other 10 scenarios remained unchanged, which indicated the stability of the site selection results and the reliability of the method. Furthermore, the criteria for ranking the first, second, and third sites were all decisive and evenly distributed. Their relative importance was balanced, although the scores of candidate sites varied under different scenarios.

**Table 3**

|       | S-1  | S-2  | S-3  | S-4  | S-5  | S-6  | S-7  | S-8  | S-9  | S-10 | S-11 |
|-------|------|------|------|------|------|------|------|------|------|------|------|
| WASPAS Q | 0.802 | 0.795 | 0.528 | 0.755 | 0.602 | 0.670 | 0.594 | 0.569 | 0.735 | 0.553 | 0.486 |
| Rank   | 1    | 2    | 10   | 3    | 6    | 5    | 7    | 9    | 4    | 8    | 11   |

|       | S-1  | S-2  | S-3  | S-4  | S-5  | S-6  | S-7  | S-8  | S-9  | S-10 | S-11 |
|-------|------|------|------|------|------|------|------|------|------|------|------|
| MOORA Q | 0.256 | 0.243 | 0.099 | 0.217 | 0.133 | 0.152 | 0.131 | 0.118 | 0.189 | 0.117 | 0.058 |
| Rank   | 1    | 2    | 10   | 3    | 7    | 5    | 6    | 8    | 4    | 9    | 11   |

|       | S-1  | S-2  | S-3  | S-4  | S-5  | S-6  | S-7  | S-8  | S-9  | S-10 | S-11 |
|-------|------|------|------|------|------|------|------|------|------|------|------|
| COPRAS Q | 0.219 | 0.203 | 0.111 | 0.185 | 0.139 | 0.151 | 0.138 | 0.121 | 0.170 | 0.126 | 0.102 |
| Rank   | 1    | 2    | 10   | 3    | 6    | 5    | 7    | 9    | 4    | 8    | 11   |

|       | S-1  | S-2  | S-3  | S-4  | S-5  | S-6  | S-7  | S-8  | S-9  | S-10 | S-11 |
|-------|------|------|------|------|------|------|------|------|------|------|------|
| TOPSIS Q | 0.426 | 0.432 | 0.240 | 0.408 | 0.289 | 0.321 | 0.299 | 0.266 | 0.373 | 0.265 | 0.213 |
| Rank   | 1    | 2    | 10   | 3    | 7    | 5    | 6    | 8    | 4    | 9    | 11   |

5. Conclusion
This study identified and assessed the most suitable landfill sites in Lanzhou and conducted a field investigation to avoid the "NIMBY effect". In doing so, the 11 selected candidate sites would not affect the health of the population, rivers, protected areas, etc., which will enhance the acceptance of the government and be of benefit to society for at least ten years. For this study, we initially established a standard evaluation system of semi-arid valley basin municipal waste landfill site selection. This was an integrated flexible and novel comprehensive framework for reducing the subjectivity and uncertainty of weight, and the fuzzy logic relation of different criteria was explored. The DEMATEL-ANP method proved to be more preferable to ANP as it could deal with all types of dependencies systematically. The simple ANP method directly constructed the network relations between the input criteria according to a scale of from 1-9, which had the subjective disadvantage of AHP. This integration framework allowed for complex issues to be explored and fed back to decision makers. Hybrid fuzzy logic is preferable to a simple method, as it can better express the fuzziness and uncertainty of criterion, to obtain more accurate results. The three density-based clustering algorithms (DBSCAN, HDBSCAN, and OPTICS) were utilized to identify 11 candidate sites for landfills, analyze their spatial distribution characteristics and reachability, and calculate the relative MSW capacities according to the area. The high consistency of the four sorting methods of MOORA, WASPAS, COPRAS, and TOPSIS fulfilled a comprehensive ranking of candidate sites. Sensitivity analysis enabled scenario simulation with different weights set by multiple criteria, which can effectively guide planners to consider the uncertainty of weights in the decision-making evaluation process to obtain more satisfactory solutions.

For subsequent research, more consideration should be given to the environmental pollution generated by selected sites. Dynamic data for landfill sites can be obtained in real time through atmospheric monitoring, soil detection, and remote imaging for standardized management. Similarly, the amount of carbon contained in landfill emissions is also a major factor that affects the environment, which warrants further study. In addition, we are currently exploring the use of various deep learning algorithms and known landfill sites that conform to the CNS for supervised or unsupervised classification. This to obtain the weight of
evaluation criteria, while inviting experts to score and modify the results to eliminate uncertainties in site selection, which is crucial for site selection research. The classification of MSW is not complete, and industrial solid waste is still divided as MSW for landfill disposal in areas with a small amount of production, such as Construction and Demolition Waste (CDW), which is difficult to manage, lacks landfill space, increases costs and has other defects, which are further issues to resolve.

Appendix

Appendix A

Table A.1

Data Format and Source.

| Dataset                | Format           | Data Source                                                                 |
|------------------------|------------------|-----------------------------------------------------------------------------|
| Groundwater depth      | Vector (Point)   | Gansu Groundwater Report (Gansu Water Resources Department) (http://slt.gansu.gov.cn/) |
| Groundwater quality    | Vector (Point)   | Gansu Groundwater Report (Gansu Water Resources Department) (http://slt.gansu.gov.cn/) |
| Groundwater richness   | Vector (Polygon) | "Gansu Hydrogeological Map"                                                 |
| Faults                 | Vector (Polyline)| (Gansu Bureau of Geology and Mineral Hydrogeology engineering Geological Exploration Institute) (http://www.gssgy.com/) |

| Layer Type       | Data Type | Source Description                                                                                                                                 |
|------------------|-----------|----------------------------------------------------------------------------------------------------------------------------------------------------|
| Earthquake points| Vector (Point) | "China Historical Earthquake Catalog" (Gansu Earthquake Agency) (http://www.gsdzj.gov.cn/)                                                              |
| DEM              | Raster    | USGS Earth Explorer (https://earthexplorer.usgs.gov/)                                                                                                  |
| Soil type        | Raster    | "The Soil Atlas of the People's Republic of China (1: 1 million)" Data Center for Resources and Environmental Sciences of the Chinese Academy of Sciences (http://www.resdc.cn/) |
| NDVI             | Raster    | MODIS (https://modis.gsfc.nasa.gov/)                                                                                                               |
| Landform type    | Raster    | "Landscape Atlas of the People's Republic of China (1: 1 million)" Data Center for Resources and Environmental Sciences of the Chinese Academy of Sciences (http://www.resdc.cn/) |
| Surface water    | Vector (Polyline) | National Catalogue Service for Geographic Information (https://webmap.cn/)                                                                          |
| Roads            | Vector (Polygon) | National Catalogue Service for Geographic Information (https://webmap.cn/) Data Center for Resources and Environmental Sciences                          |
| Land use type    | Raster    | of the Chinese Academy of Sciences (http://www.resdc.cn/)                                                                                           |
| Settlements      | Vector (Point) | National Catalogue Service for Geographic Information (https://webmap.cn/)                                                                          |
| Attribute               | Type          | Source                                                                 |
|------------------------|---------------|------------------------------------------------------------------------|
| Precipitation          | Raster        | Data Center for Resources and Environmental Sciences of the Chinese Academy of Sciences (http://www.resdc.cn/) |
| Temperature            | Raster        | Data Center for Resources and Environmental Sciences of the Chinese Academy of Sciences (http://www.resdc.cn/) |
| Ecosystem service value| Raster        | Data Center for Resources and Environmental Sciences of the Chinese Academy of Sciences (http://www.resdc.cn/) |
| Population density     | Raster        | Data Center for Resources and Environmental Sciences of the Chinese Academy of Sciences (http://www.resdc.cn/) |
| GDP                    | Raster        | Data Center for Resources and Environmental Sciences of the Chinese Academy of Sciences (http://www.resdc.cn/) |
| Airports               | Vector (Point)| Crawled POI data Official website of Gold Maps (https://lbs.amap.com/)    |
| Ecological function    | Vector (Polygon)| Portal website of Gansu Forestry and Grass Bureau and its administrative departments (http://lycy.gansu.gov.cn/) |
| Criteria       | Sub-criteria | Attribute | Rank | Conditions to be met                                                                 | Type     |
|----------------|--------------|-----------|------|--------------------------------------------------------------------------------------|----------|
| Hydrogeo       | Groundwater depth | <5        | 1    | The landfill should develop at locations with sufficient groundwater depth (Rezaeisabzevar et al., 2020) | positive |
| logical B1    | C1 (m)       | 5-20      | 2    |                                                                                      |          |
|                |              | 20-50     | 3    |                                                                                      |          |
|                |              | 50-70     | 4    |                                                                                      |          |
|                |              | >70       | 5    |                                                                                      |          |
| Groundwater quality | I | 1         | 1    | The landfill should be located in areas with poor water quality (Przydatek and Kanownik, 2019) | negative |
|                | II           | 2         | 2    | poor water quality (Przydatek and Kanownik, 2019)                                    |          |
|                | III          | 3         | 3    |                                                                                      |          |
|                | IV           | 4         | 4    |                                                                                      |          |
|                | V            | 5         | 5    |                                                                                      |          |
| Groundwater richness C3 (m³/L) | >1000 | 1         | 1    | The landfill should be located in an area with low groundwater richness (Sener et al., 2011) | positive |
|                | 600-1000     | 2         | 2    | with low groundwater richness (Sener et al., 2011)                                    |          |
|                | 300-600      | 3         | 3    |                                                                                      |          |
|                | 100-300      | 4         | 4    |                                                                                      |          |
|                | <100         | 5         | 5    |                                                                                      |          |
| Distance from faults | <1 | 1         | 1    | The landfill avoided in areas with active geological structures or other underground terrain (Eskandari et al., 2012) | negative |
| C4 (km)        | 3-1          | 2         | 2    |                                                                                      |          |
|                | 5-3          | 3         | 3    |                                                                                      |          |
|                | 6-5          | 4         | 4    |                                                                                      |          |
|                | >6           | 5         | 5    |                                                                                      |          |
| Distance from earthquake points $C_3$ (km) | 1 | The landfill should be located far away from the earthquake point to reduce the possibility of natural disasters (Eskandari et al., 2012) |
|-----------------------------------------|---|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <5                                      | 1 |                                                                                                                                  |
| 5-15                                    | 2 |                                                                                                                                                                                                  |
| 15-25                                   | 3 |                                                                                                                                                                                                  |
| 25-30                                   | 4 |                                                                                                                                                                                                  |
| >30                                     | 5 |                                                                                                                                                                                                  |
| Morphological Elevation $C_5$ (m) >2000  | 1 | The landfill should not be located in high-altitude areas (Sener et al., 2010)                                                                                                                   |
| 1750-2000                               | 2 |                                                                                                                                                                                                  |
| 1500-1750                               | 3 |                                                                                                                                                                                                  |
| 1250-1500                               | 4 |                                                                                                                                                                                                  |
| 1000-1250                               | 5 |                                                                                                                                                                                                  |
| Slope $C_7$ (%) >60                     | 1 | The landfill should be located in a low slope area (Chabuk et al., 2016)                                                                                                                        |
| 40-60                                   | 2 |                                                                                                                                                                                                  |
| 20-40                                   | 3 |                                                                                                                                                                                                  |
| 10-20                                   | 4 |                                                                                                                                                                                                  |
| <10                                     | 5 |                                                                                                                                                                                                  |
| Soil type $C_8$                         | 1 | The landfill should be located in areas with sandy soil (Soroudi et al., 2018)                                                                                                                  |
| Soil Type                                      | Rank |
|-----------------------------------------------|------|
| Semi-aqueous soil, rock soil, calcareous soil, primordial soil, semi-leached soil | 2    |
| Arid soil                                     | 3    |
| Alpine soil, desert soil                      | 4    |
| Saline soil                                   | 5    |

| NDVI $C_9$ | Range | Score |
|------------|-------|-------|
| >0.8       | 1     | Positive |
| 0.5-0.8    | 2     |         |
| 0.3-0.5    | 3     |         |
| 0.2-0.3    | 4     |         |
| <0.2       | 5     |         |

The landfill should be located in an area with low vegetation coverage (Kara and Doratli, 2012) in a positive NDVI range.

| Landform type $C_{10}$ | Score |
|-------------------------|-------|
| Medium and large rolling mountains | 1 |
| Small rolling mountain | 2 |
| hills                   | 3    |
| Terraces                | 4    |
| Plains                  | 5    |

The landfill should be located in the plain area (Sureshkumar et al., 2017) in a negative landform type range.

| Environmental Distance from surface water $C_{11}$ | Score |
|----------------------------------------------------|-------|
| <0.5                                               | 1     |
| 1-0.5                                              | 2     |

The landfill should not be located near ambient surface water such as ponds, lakes, in a negative environmental distance range.
| C_{12} (km) | Distance from roads | Water, snow, farmland, forestland | Bare land | Water, snow, farmland, forestland | Bare land |
|-------------|---------------------|----------------------------------|-----------|----------------------------------|-----------|
| 1-2         | 1-2-1.5             | 1-2                              | 1         | 0.5-1                             | 2         |
| >2          | 2                   | 3                                | 3         | 1                                | 4         |
| >=3         | 3                   | 4                                | 4         | >=3                              | 5         |

In view of the high transportation costs, the landfill should not be too far away from the road network (Chabuk et al., 2016). The landfill should be located in unused areas such as bare land (Motlagh and Sayadi, 2015) or in arid areas (Augusto et al., 2019). The landfill should not be located near residential areas (Wang et al., 2009).
| Temperature (°C) | C16  | 180-200 | 4       |
|-----------------|-------|---------|---------|
|                 | <180  |         | 5       |
| Temperature     | C16   | <3 | >10      | 1       |
|                 |       | The landfill should be located in a mild area | negative |
| Socio-economic  | service | >15000 | 1       | The landfill should be as cheap as possible, negative |
| Ecosystem value  | C17   | 10000-15000 | 2       |
|                 |       | 5000-10000 | 3       |
|                 |       | 3000-5000 | 4       |
|                 |       | <3000    | 5       |
| Population density | C18 | >300    | 1       | The landfill should be located in areas with low population density | positive |
|                 |       | 200-300  | 2       |
|                 |       | 150-200  | 3       |
|                 |       | 100-150  | 4       |
|                 |       | <100     | 5       |
| GDP             | C19   | >1000    | 1       | The landfill should be located in areas with low GDP | negative |
|                 |       | <300     | 2       |
|                 |       | 600-300  | 3       |
|                 |       | 800-600  | 4       |
| Distance from airports C<sub>20</sub> (km) | The landfill is a potential risk to aviation safety because they attract flocks of birds. | Therefore, landfills should not be located near airports (Wang et al., 2009) |
|----------------------------------------|----------------------------------------------------------------------------------|--------------------------------------------------------------------------|
| <3                                     | 1                                                                                | negative                                                                 |
| 6-3                                    | 2                                                                                |                                                                          |
| 9-6                                    | 3                                                                                | positive                                                                 |
| 12-9                                   | 4                                                                                |                                                                          |
| >12                                    | 5                                                                                |                                                                          |
| <1                                     | 1                                                                                | positive                                                                 |
| 4-1                                    | 2                                                                                |                                                                          |
| 7-4                                    | 3                                                                                |                                                                          |
| 10-7                                   | 4                                                                                |                                                                          |
| >10                                    | 5                                                                                |                                                                          |
|   | $B_1$ | $B_2$ | $B_3$ | $B_4$ | $B_5$ |
|---|-------|-------|-------|-------|-------|
| $C_1$ | 0.1513 | 0.2485 | 0.1242 | 0.0466 | 0.2178 |
| $C_2$ | 0.0763 | 0.0649 | 0.0716 | 0.0566 | 0.0950 |
| $C_3$ | 0.1399 | 0.1128 | 0.2126 | 0.0603 | 0.2078 |
| $C_4$ | 0.2230 | 0.0393 | 0.1049 | 0.0796 | 0.1980 |
| $C_5$ | 0.0954 | 0.0616 | 0.0482 | 0.0333 | 0.0428 |
| $C_6$ | 0.1137 | 0.0386 | 0.1090 | 0.0972 | 0.0471 |
| $C_7$ | 0.1127 | 0.0655 | 0.0983 | 0.1127 | 0.0655 |
| $C_8$ | 0.0872 | 0.0670 | 0.0803 | 0.0676 | 0.0666 |
| $C_9$ | 0.0796 | 0.0395 | 0.0877 | 0.0688 | 0.0282 |

Table B.2

The total influence matrix of the criteria ($T_C$).
Table B.3

The total influence matrix of the criteria ($T_B$).

|     | $B_1$ | $B_2$ | $B_3$ | $B_4$ | $B_5$ |
|-----|------|------|------|------|------|
| $B_1$ | 0.1100 | 0.3247 | 0.0529 | 0.0151 | 0.0151 |
| $B_2$ | 0.3851 | 0.1365 | 0.1850 | 0.0529 | 0.0529 |
| $B_3$ | 0.4757 | 0.3058 | 0.1893 | 0.3398 | 0.3398 |
| $B_4$ | 0.2265 | 0.0901 | 0.1775 | 0.0507 | 0.0507 |
| $B_5$ | 0.1359 | 0.0874 | 0.3398 | 0.0971 | 0.0971 |
Fig. C.1. A comparison of values of the candidate sites in each cluster for the DBSCAN, HDBSCAN, and OPTICS.

Fig. C.2. The reachability chart of OPTICS algorithm, different colors represent different clusters.

Appendix D

Table D.1

"Construction Standard of MSW Landfill Disposal Engineering Project". The landfill is divided into four levels according to the area of the landfill. The smaller the area, the higher the level, and the lower the amount of MSW to be disposed.
| Landfill | Area (Km²) | I  | II  | III | IV  |
|----------|------------|----|-----|-----|-----|
|          |            | >12| 5-12| 2-5 | 1-2 |
| Amount of MSW (Tons/day) | >1200 | 500-1200 | 200-500 | <200 |

**Table D.2**

Candidate site latitude, longitude, area, and MSW disposal capacity. S-1 and S-2 had the highest MSW disposal capacities, S-4, S-6, and S-10 had the lowest MSW disposal capacities.

| Country/District | Candidate site | Longitude | Latitude | Area (Km²) | Amount of MSW (Tons/day) |
|-----------------|----------------|-----------|----------|------------|--------------------------|
| Yongdeng        | S-3            | 103°31′25″E | 36°47′43″N | 40.3       | >1200                    |
|                 | S-5            | 103°33′12″E | 36°30′37″N | 29.9       | >1200                    |
|                 | S-7            | 103°37′14″E | 36°20′52″N | 28.2       | >1200                    |
|                 | S-8            | 103°25′47″E | 36°33′12″N | 27.6       | >1200                    |
|                 | S-1            | 103°58′40″E | 36°29′14″N | 41.4       | >1200                    |
| Gaolan          | S-4            | 103°53′15″E | 36°39′55″N | 27.7       | >1200                    |
|                 | S-6            | 103°48′19″E | 36°32′35″N | 15.3       | >1200                    |
| Yuzhong         | S-2            | 104°27′50″E | 36°22′56″N | 35.5       | >1200                    |
| Honggu          | S-9            | 103°12′11″E | 36°10′58″N | 9.8        | 500-1200                 |
| Xigu            | S-10           | 103°27′46″E | 36°11′14″N | 3.7        | 200-500                  |
| Anning          | S-11           | 103°37′05″E | 36°8′37″N  | 2.6        | 200-500                  |
| Qilihe          | -              | -          | -         | -          | -                        |
| Chengguan       | -              | -          | -         | -          | -                        |
### Table E.1

Weighting scenarios and Spearman's correlation coefficient values of WASPAS, MOORA, COPRAS, and TOPSIS.

| Scenario | Scenario description                                           | Spearman's correlation coefficient |
|----------|---------------------------------------------------------------|-------------------------------------|
|          |                                                               | WASPAS  MOORA  COPRAS  TOPSIS       |
| 1        | original weight                                               | 1        1        1        1      |
| 2        | The weight of the first-ranking is substituted with the second-ranking | 1        1        1        1      |
| 3        | The weight of the first-ranking is substituted with the third-ranking | 1        1        1        1      |
| 4        | The weight of the first-ranking is substituted with the fourth-ranking | 0.9428   0.8857  0.9428  0.8857  |
| 5        | The weight of the second-ranking is substituted with the third-ranking | 1        1        1        1      |
| 6        | The weight of the second-ranking is substituted with the fourth-ranking | 0.9428   0.9428  0.9428  0.9428  |
| 7        | Omitting the first-ranking criterion                           | 0.8857   0.9428  0.8857  0.9428  |
| 8        | Omitting the second-ranking criterion                          | 1        1        1        1      |
| 9        | Omitting the third-ranking criterion                           | 1        1        1        1      |
| 10       | Increasing the first-ranking weight                            | 1        1        1        1      |
Decreasing the first-ranking weight by 5%

Increasing the second-ranking weight by 5%

Decreasing the second-ranking weight by 5%

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**Fig. E.2.** The left figure shows a comparison of the values of WASPAS for the candidate sites in each scenario. The right figure shows a comparison of the values of MOORA for the candidate sites in each scenario.

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**References**

Afzali, A., Sabri, S., Rashid, M., Samani, J.M.V., Ludin, A.N.M., 2014. Inter-Municipal Landfill Site Selection Using Analytic Network Process. Water Resources Management 28(8), 2179-2194. [https://doi.org/10.1007/s11269-014-0605-3](https://doi.org/10.1007/s11269-014-0605-3).

Ahmed, F., Ahmad, G., Brand, T., Zeeb, H., 2020. Key indicators for appraising adolescent sexual and
reproductive health in South Asia: international expert consensus exercise using the Delphi technique. Global Health Action 13(1). https://doi.org/10.1080/16549716.2020.1830555.

Aksoy, E., San, B.T., 2016. USING MCDA AND GIS FOR LANDFILL SITE SELECTION: CENTRAL DISTRICTS OF ANTALYA PROVINCE, in: Halounova, L., Li, S., Safar, V., Tomkova, M., Rapant, P., Brazdil, K., Shi, W., Anton, F., Liu, Y., Stein, A., Cheng, T., Pettit, C., Li, Q.Q., Sester, M., Mostafavi, M.A., Madden, M., Tong, X., Brovelli, M.A., HaeKyong, K., Kawashima, H., Coltekin, A. (Eds.), Xxiii Isprs Congress, Commission Ii. pp. 151-157.

Alavi, N., Goudarzi, G., Babaei, A.A., Jaafarzadeh, N., Hosseinzadeh, M., 2013. Municipal solid waste landfill site selection with geographic information systems and analytical hierarchy process: a case study in Mahshahr County, Iran. Waste Management & Research 31(1), 98-105. https://doi.org/10.1177/0734242x12456092.

Aracil, C., Haro, P., Fuentes-Cano, D., Gomez-Barea, A., 2018. Implementation of waste-to-energy options in landfill-dominated countries: Economic evaluation and GHG impact. Waste Management 76, 443-456. https://doi.org/10.1016/j.wasman.2018.03.039.

Asefi, H., Zhang, Y., Lim, S., Maghrebi, M., 2020a. An integrated approach to suitability assessment of municipal solid waste landfills in New South Wales, Australia. Australasian Journal Of Environmental Management 27(1), 63-83. https://doi.org/10.1080/14486563.2020.1719438.

Asefi, H., Zhang, Y., Lim, S., Maghrebi, M., Shahparvari, S., 2020b. A multi-criteria decision support framework for municipal solid waste landfill siting: a case study of New South Wales (Australia). Environmental Monitoring and Assessment 192(11). https://doi.org/10.1007/s10661-020-08565-y.

Augusto, P.A., Castelo-Grande, T., Merchan, L., Estevez, A.M., Quintero, X., Barbosa, D., 2019. Landfill leachate treatment by sorption in magnetic particles: preliminary study. Science Of the Total Environment 648, 636-668. https://doi.org/10.1016/j.scitotenv.2018.08.056.

Bahrani, S., Ebadi, T., Ehsani, H., Yousefi, H., Maknoon, R., 2016. Modeling landfill site selection by multi-criteria decision making and fuzzy functions in GIS, case study: Shabestar, Iran. Environmental Earth Sciences 75(4). https://doi.org/10.1007/s12665-015-5146-4.

Beskese, A., Demir, H.H., Ozcan, H.K., Okten, H.E., 2015. Landfill site selection using fuzzy AHP and fuzzy
TOPSIS: a case study for Istanbul. Environmental Earth Sciences 73(7), 3513-3521. https://doi.org/10.1007/s12665-014-3635-5.

Brauers, W.K.M., Zavadskas, E.K., 2006. The MOORA method and its application to privatization in a transition economy. Control and Cybernetics 35(2), 445-469.

Breunig, M.M., Kriegel, H.-P., Sander, J., 2000. Fast Hierarchical Clustering Based on Compressed Data and OPTICS. Lecture Notes in Computer Science <D> 1910, 232-242.

Chabuk, A., Al-Ansari, N., Hussain, H.M., Knutsson, S., Pusch, R., 2016. Landfill site selection using geographic information system and analytical hierarchy process: A case study Al-Hillah Qadhaa, Babylon, Iraq. Waste Management & Research 34(5), 427-437. https://doi.org/10.1177/0734242x16633778.

Chamchali, M.M., Ghazifard, A., 2019. The use of fuzzy logic spatial modeling via GIS for landfill site selection (case study: Rudbar-Iran). Environmental Earth Sciences 78(10). https://doi.org/10.1007/s12665-019-8296-y.

Chang, B., Chang, C.-W., Wu, C.-H., 2011. Fuzzy DEMATEL method for developing supplier selection criteria. Expert Systems with Applications 38(3), 1850-1858. https://doi.org/10.1016/j.eswa.2010.07.114.

Demoussouka, O.E., Vavatsikos, A.P., Anagnostopoulos, K.P., 2013. Suitability analysis for siting MSW landfills and its multicriteria spatial decision support system: Method, implementation and case study. Waste Management 33(5), 1190-1206. https://doi.org/10.1016/j.wasman.2013.01.030.

Eghtesadifard, M., Afkhami, P., Bazyar, A., 2020. An integrated approach to the selection of municipal solid waste landfills through GIS, K-Means and multi-criteria decision analysis. Environ. Res. 185, 16. https://doi.org/10.1016/j.envres.2020.109348.

Eghtesadifard, M., Afkhami, P., Bazyar, A., 2020. An integrated approach to the selection of municipal solid waste landfills through GIS, K-Means and multi-criteria decision analysis. Environ. Res. 185. https://doi.org/10.1016/j.envres.2020.109348.

Eskandari, M., Homae, M., Mahmodi, S., 2012. An integrated multi criteria approach for landfill siting in a conflicting environmental, economical and socio-cultural area. Waste Management 32(8), 1528-1538. https://doi.org/10.1016/j.wasman.2012.03.014.

Farahbakhsh, A., Forghani, M.A., 2019. Sustainable location and route planning with GIS for waste sorting
centers, case study: Kerman, Iran. Waste Management & Research 37(3), 287-300. https://doi.org/10.1177/0734242x18815950.

Ferronato, N., Torretta, V., 2019. Waste Mismanagement in Developing Countries: A Review of Global Issues. International Journal of Environmental Research and Public Health 16(6). https://doi.org/10.3390/ijerph16061060.

Feyz, S., Khanmohammadi, M., Abedinzadeh, N., Aalipour, M., 2019. Multi-criteria decision analysis FANP based on GIS for siting municipal solid waste incineration power plant in the north of Iran. Sust. Cities Soc. 47, 12. https://doi.org/10.1016/j.scs.2019.101513.

Gbanie, S.P., Tengbe, P.B., Momoh, J.S., Medo, J., Kabba, V.T.S., 2013. Modelling landfill location using Geographic Information Systems (GIS) and Multi-Criteria Decision Analysis (MCDA): Case study Bo, Southern Sierra Leone. Applied Geography 36, 3-12. https://doi.org/10.1016/j.apgeog.2012.06.013.

Gorsevski, P.V., Donevska, K.R., Mitrovski, C.D., Frizado, J.P., 2012. Integrating multi-criteria evaluation techniques with geographic information systems for landfill site selection: A case study using ordered weighted average. Waste Management 32(2), 287-296. https://doi.org/10.1016/j.wasman.2011.09.023.

Gui, Z., Peng, D., Wu, H., Long, X., 2020. MSGC: Multi-scale grid clustering by fusing analytical granularity and visual cognition for detecting hierarchical spatial patterns. Future Generation Computer Systems-the International Journal of Escience 112, 1038-1056. https://doi.org/10.1016/j.future.2020.06.053.

Hanine, M., Boutkhoum, O., Tikniouine, A., Agouti, T., 2016. Comparison of fuzzy AHP and fuzzy TODIM methods for landfill location selection. Springerplus 5. https://doi.org/10.1186/s40064-016-2131-7.

Hariz, H.A., Donmez, C.C., Sennaroglu, B., 2017. Siting of a central healthcare waste incinerator using GIS-based Multi Criteria Decision Analysis. Journal of Cleaner Production 166, 1031-1042. https://doi.org/10.1016/j.jclepro.2017.08.091.

He, S., Wang, X., Dong, J., Wei, B., Duan, H., Jiao, J., Xie, Y., 2019. Three-Dimensional Urban Expansion Analysis of Valley-Type Cities: A Case Study of Chengguan District, Lanzhou, China. Sustainability 11(20). https://doi.org/10.3390/su11205663.

Hossaini, N., Reza, B., Akhtar, S., Sadiq, R., Hewage, K., 2015. AHP based life cycle sustainability assessment
(LCSA) framework: a case study of six storey wood frame and concrete frame buildings in Vancouver. Journal of Environmental Planning and Management 58(7), 1217-1241. https://doi.org/10.1080/09640568.2014.920704.

Hu, S., He, Z., Wu, L., Yin, L., Xu, Y., Cui, H., 2020. A framework for extracting urban functional regions based on multiprototype word embeddings using points-of-interest data. Computers Environment and Urban Systems 80. https://doi.org/10.1016/j.compenvurbsys.2019.101442.

GBGMHEGEI, 2015. Gansu Bureau of Geology and Mineral Hydrogeology Engineering Geological Exploration Institute (China). http://www.gssgy.com/ (Accessed 11 December 2019).

GDM, 2019. Gaode Map (China). https://lbs.amap.com/ (Accessed 14 December 2019).

GEA, 2015. Gansu Earthquake Agency online portal (China). http://www.gsdzj.gov.cn/ (Accessed 12 December 2019).

GESB, 2009. Gansu Environmental Statistics Bulletin (China). http://sthj.gansu.gov.cn/ (Accessed 15 December 2019).

GFGB, 2015. Gansu Forestry and Grass Bureau (China). http://lycy.gansu.gov.cn/ (Accessed 25 December 2019).

GWRD, 2019. Gansu Water Resources Department (China). http://slt.gansu.gov.cn/ (Accessed 18 December 2019).

Isalou, A.A., Zamani, V., Shahmoradi, B., Alizadeh, H., 2013. Landfill site selection using integrated fuzzy logic and analytic network process (F-ANP). Environmental Earth Sciences 68(6), 1745-1755. https://doi.org/10.1007/s12665-012-1865-y.

Juang, C.H., Dijkstra, T., Wasowski, J., Meng, X., 2019. Loess geohazards research in China: Advances and challenges for mega engineering projects. Engineering Geology 251, 1-10. https://doi.org/10.1016/j.enggeo.2019.01.019.

Kamdar, I., Ali, S., Bennui, A., Techato, K., Jutidamrongphan, W., 2019. Municipal solid waste landfill siting using an integrated GIS-AHP approach: A case study from Songkhla, Thailand. Resources Conservation And Recycling 149, 220-235. https://doi.org/10.1016/j.resconrec.2019.05.027.
Kara, C., Doratli, N., 2012. Application of GIS/AHP in siting sanitary landfill: a case study in Northern Cyprus. Waste Management & Research 30(9), 966-980. https://doi.org/10.1177/0734242x12453975.

Karakus, C.B., Demiroglu, D., Coban, A., Ulutas, A., 2020. Evaluation of GIS-based multi-criteria decision-making methods for sanitary landfill site selection: the case of Sivas city, Turkey. Journal Of Material Cycles And Waste Management 22(1), 254-272. https://doi.org/10.1007/s10163-019-00935-0.

Karakus, C.B., Demiroglu, D., Coban, A., Ulutas, A., 2020. Evaluation of GIS-based multi-criteria decision-making methods for sanitary landfill site selection: the case of Sivas city, Turkey. Journal Of Material Cycles And Waste Management 22(1), 254-272. https://doi.org/10.1007/s10163-019-00935-0.

Karimi, N., Richter, A., Ng, K.T.W., 2020. Siting and ranking municipal landfill sites in regional scale using nighttime satellite imagery. Journal of Environmental Management 256. https://doi.org/10.1016/j.jenvman.2019.109942.

Khan, M.M.-U.-H., Vaezi, M., Kumar, A., 2018. Optimal siting of solid waste-to-value-added facilities through a GIS-based assessment. Science Of the Total Environment 610, 1065-1075. https://doi.org/10.1016/j.scitotenv.2017.08.169.

Krcmar, D., Tenodi, S., Grba, N., Kerkez, D., Watson, M., Roncevic, S., Dalmacija, B., 2018. Preremedial assessment of the municipal landfill pollution impact on soil and shallow groundwater in Subotica, Serbia. Science of the Total Environment 615, 1341-1354. https://doi.org/10.1016/j.scitotenv.2017.09.283.

Li, J., Wang, Z., Chen, L., Lian, L., Li, Y., Zhao, L., Zhou, S., Mao, X., Huang, T., Gao, H., Ma, J., 2020. WRF-Chem simulations of ozone pollution and control strategy in petrochemical industrialized and heavily polluted Lanzhou City, Northwestern China. Science of the Total Environment 737. https://doi.org/10.1016/j.scitotenv.2020.139835.

Lima, R.M., Santos, A.H.M., Pereira, C.R.S., Flauzino, B.K., Pereira, A.C.O.S., Nogueira, F.J.H., Valverde, J.A.R., 2018. Spatially distributed potential of landfill biogas production and electric power generation in Brazil. Waste Management 74, 323-334. https://doi.org/10.1016/j.wasman.2017.12.011.

Liu, H., Long, H., Li, X., 2020. Identification of critical factors in construction and demolition waste recycling by the grey-DEMATEL approach: a Chinese perspective. Environmental Science and Pollution Research 27(8), 8507-8525. https://doi.org/10.1007/s11356-019-07498-5.

Mahmood, K., Batool, S.A., Chaudhary, M.N., Ul-Haq, Z., 2017. Ranking criteria for assessment of municipal solid waste dumping sites. Archives of Environmental Protection 43(1), 95-105. https://doi.org/10.1515/aep-
Malakahmad, A., Abualqumboz, M.S., Kutty, S.R.M., Abunama, T.J., 2017. Assessment of carbon footprint emissions and environmental concerns of solid waste treatment and disposal techniques; case study of Malaysia. Waste Management 70, 282-292. https://doi.org/10.1016/j.wasman.2017.08.044.

MODIS, 2018. MODIS (China). https://modis.gsfc.nasa.gov/ (Accessed 20 December 2019).

Motlagh, Z.K., Sayadi, M.H., 2015. Siting MSW landfills using MCE methodology in GIS environment (Case study: Birjand plain, Iran). Waste Management 46, 322-337. https://doi.org/10.1016/j.wasman.2015.08.013.

NCSGI, 2015. National Catalogue Service for Geographic Information (China). https://webmap.cn/ (Accessed 22 December 2019).

NSFTOS, 2017. National Standard Full Text Open System (China). http://opendt.samr.gov.cn/bzgk/gb/ (Accessed 20 February 2020).

Ozkan, B., Ozceylan, E., Saricicek, I., 2019. GIS-based MCDM modeling for landfill site suitability analysis: A comprehensive review of the literature. Environmental Science And Pollution Research 26(30), 30711-30730. https://doi.org/10.1007/s11356-019-06298-1.

Pamucar, D., Bozanic, D., Lukovac, V., Komazec, N., 2018. NORMALIZED WEIGHTED GEOMETRIC BONFERRONI MEAN OPERATOR OF INTERVAL ROUGH NUMBERS - APPLICATION IN INTERVAL ROUGH DEMATEL-COPRAS MODEL. Facta Universitatis-Series Mechanical Engineering 16(2), 171-191. https://doi.org/10.22190/fume180503018p.

Przydatek, G., Kanownik, W., 2019. Impact of small municipal solid waste landfill on groundwater quality. Environmental Monitoring And Assessment 191(3). https://doi.org/10.1007/s10661-019-7279-5.

Rahimi, S., Hafezalkotob, A., Monavari, S.M., Hafezalkotob, A., Rahimi, R., 2020. Sustainable landfill site selection for municipal solid waste based on a hybrid decision-making approach: Fuzzy group BWM-MULTIMOORA-GIS. Journal of Cleaner Production 248. https://doi.org/10.1016/j.jclepro.2019.119186.

Rashid, T., Beg, I., Husnine, S.M., 2014. Robot selection by using generalized interval-valued fuzzy numbers with TOPSIS. Applied Soft Computing 21, 462-468. https://doi.org/10.1016/j.asoc.2014.04.002.
RESDC, 2015. Resource and Environmental Science and Data Center, Chinese Academy of Sciences (China).

http://www.resdc.cn/ (Accessed 28 December 2019).

Rezaeisabzevar, Y., Bazargan, A., Zohourian, B., 2020. Landfill site selection using multi criteria decision making: Influential factors for comparing locations. J. Environ. Sci. 93, 170-184.
https://doi.org/10.1016/j.jes.2020.02.030.

Salabun, W., Watrobski, J., Shekhovtsov, A., 2020. Are MCDA Methods Benchmarkable? A Comparative Study of TOPSIS, VIKOR, COPRAS, and PROMETHEE II Methods. Symmetry-Basel 12(9).
https://doi.org/10.3390/sym12091549.

Sener, S., Sener, E., Karaguzel, R., 2011. Solid waste disposal site selection with GIS and AHP methodology: a case study in Senirkent-Uluborlu (Isparta) Basin, Turkey. Environmental Monitoring And Assessment 173(1-4), 533-554. https://doi.org/10.1007/s10661-010-1403-x.

Sener, S., Sener, E., Nas, B., Karaguzel, R., 2010. Combining AHP with GIS for landfill site selection: A case study in the Lake Beysehir catchment area (Konya, Turkey). Waste Management 30(11), 2037-2046.
https://doi.org/10.1016/j.wasman.2010.05.024.

Soltani, A., Hewage, K., Reza, B., Sadiq, R., 2015. Multiple stakeholders in multi-criteria decision-making in the context of Municipal Solid Waste Management: A review. Waste Management 35, 318-328.
https://doi.org/10.1016/j.wasman.2014.09.010.

Soroudi, M., Omrani, G., Moataar, F., Jozi, S.A., 2018. Modelling an Integrated Fuzzy Logic and Multi-Criteria Approach for Land Capability Assessment for Optimized Municipal Solid Waste Landfill Siting Yeast. Polish Journal Of Environmental Studies 27(1), 313-323. https://doi.org/10.15244/pjoes/69576.

Spigolon, L.M.G., Giannotti, M., Larocca, A.P., Russo, M.A.T., Souza, N.D., 2018. Landfill siting based on optimisation, multiple decision analysis, and geographic information system analyses. Waste Management & Research 36(7), 606-615. https://doi.org/10.1177/0734242x18773538.

Sureshkumar, M., Sivakumar, R., Nagarajan, M., 2017. SELECTION OF ALTERNATIVE LANDFILL SITE IN KANCHIPURAM, INDIA BY USING GIS AND MULTICRITERIA DECISION ANALYSIS. Applied Ecology And Environmental Research 15(1), 627-636. https://doi.org/10.15666/aeer/1501_627636.
The World Bank, 2012. What a waste: a global review of solid waste management. Retrieved from <http://go.worldbank.org/BCQEP0TMO0>.

USGS, 2015. United States Geological Survey (US). https://earthexplorer.usgs.gov/ (Accessed 26 December 2019).

Uyan, M., 2014. MSW landfill site selection by combining AHP with GIS for Konya, Turkey. Environmental Earth Sciences 71(4), 1629-1639. https://doi.org/10.1007/s12665-013-2567-9.

Wang, G., Qin, L., Li, G., Chen, L., 2009. Landfill site selection using spatial information technologies and AHP: A case study in Beijing, China. Journal Of Environmental Management 90(8), 2414-2421. https://doi.org/10.1016/j.jenvman.2008.12.008.

Zavadskas, E.K., Turskis, Z., Antucheviciene, J., Zakarevicius, A., 2012. Optimization of Weighted Aggregated Sum Product Assessment. Elektronika Ir Elektrotechnika 122(6), 3-6. https://doi.org/10.5755/j01.eee.122.6.1810.

Zhang, T., Shi, J., Qian, X., Ai, Y., 2019. Temperature and Gas Pressure Monitoring and Leachate Pumping Tests in a Newly Filled MSW Layer of a Landfill. International Journal Of Environmental Research 13(1), 1-19. https://doi.org/10.1007/s41742-018-0157-0.

Zhao, S., Yu, Y., Du, Z., Yin, D., Yang, J., Dong, L., Li, P., 2020. Size-resolved carbonaceous aerosols at near surface level and the hilltop in a typical valley city, China. Atmospheric Pollution Research 11(1), 129-140. https://doi.org/10.1016/j.apr.2019.09.022.