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Integration of Geographic Information Systems and Multicriteria Decision Analysis for Landfill Site Selection: A Case Study of Kirkuk Governorate, Iraq

Hana Kareem Shekho *, *Muntadher Aidi Shareef*
Engineering Techniques Department, Engineering College of Kirkuk, Northern Technical University, Kirkuk, Iraq.

Keywords:
Landfill; Weighted average; Multicriteria; GIS.

Highlights:

- *Landfill availability lands were selected according to specific criteria.*
- *Landfill suitability sites were selected according to land slope, soil type, and stable groundwater level factors.*
- *The land cover map of the study was established using the random forest classification method.*

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***Corresponding author:**
Hana Kareem Shekho
Department of Chemical Engineering, College of Engineering, Tikrit University, Tikrit, Iraq.

Abstract: Waste landfills are dangerous to the surrounding environment and human health, so choosing their locations according to scientific methods is necessary. This research aims to find available and suitable sites for constructing a landfill in Kirkuk and its neighboring areas, i.e., Taza and Laylan districts. The present study combines many factors, such as the road network, the villages surrounding the cities, oil pipelines, hospitals, and the electrical transportation network. In addition, the present study extracted the urban areas and water bodies using the random forest classification method to find the constraint areas. The basic criteria were used to find the most suitable areas for landfill construction after weighting using the weighted average method, which included the stable groundwater level, soil type, and land slope. The findings revealed that the available land and constrained land areas were 613.56 km² (44.84%) and 754.78 km² (55.16%), respectively. Moreover, the findings of land suitability were classified as very low, low, moderate, high, or very high suitability. The medium suitability had an area of (189.75 km²), while the high and very high suitability areas covered 187.69 km² and 153.94 km², respectively. Subsequently, four specific sites (two sites in Laylan, one in Taza, and one in Kirkuk City) were proposed for constructing new landfills in the area.

تكامل نظم المعلومات الجغرافية وتحليل قرار متعدد المعايير لاختيار موقع مكب النفايات: دراسة حالة لمحافظة كركوك، العراق

هناء كريم شيخو، منتظر عايد شريف
قسم التقنيات الهندسية/ كلية هندسة كركوك/ الجامعة التقنية الشمالية/ كركوك – العراق.

الخلاصة

تعتبر مدافن النفايات خطرة على البيئة المحيطة وصحة الإنسان، لذلك من الضروري اختيار مواقعها وفقا للأساليب العلمية. يهدف هذا البحث إلى إيجاد مواقع متاحة ومناسبة لبناء مكب نفايات في كركوك والمناطق المجاورة لها، منطقتي تازة وليلان. في هذه الدراسة، تم الجمع بين العديد من العوامل، مثل شبكة الطرق، والقرى المحيطة بالمدن، وأنابيب النفط، والمستشفيات، وشبكة النقل الكهربائي، بالإضافة إلى استخراج المناطق الحضرية والمسطحات المائية بطريقة التصنيف Random Forest، للعثور على المناطق المعوقة. تم استخدام المعايير الأساسية للعثور على أنسب المناطق لبناء مدافن النفايات بعد الترجيح باستخدام طريقة المتوسط المرجح، والتي تضمنت مستوى المياه الجوفية المستقر ونوع التربة ومنحدر الأرض. وكشفت النتائج أن مساحات الأراضي المتاحة والأراضي المقيدة كانت ٦١٣,٥٦ كم^{٢} (٤٤,٨٤٪) و٧٥٤,٧٨ كم^{٢} (٥٥,١٦٪)، على التوالي، في هذه الدراسة. علاوة على ذلك، تم تصنيف نتائج ملاءمة الأرض على أنها منخفضة جدا، أو منخفضة، أو معتدلة، أو عالية، أو عالية جدا. تبلغ مساحة الملاءمة المتوسطة (١٨٩,٧٥ كم^{٢})، بينما تغطي مناطق الملاءمة العالية والعالية جدا ١٨٧,٦٩ كم^{٢} و١٥٣,٩٤ كم^{٢}على التوالي. بعد ذلك، تم اختيار أربعة مواقع محددة كمقترحات لبناء مدافن جديدة في المنطقة (اثنان منها في ليلان وواحدة في تازة والأخرى في مدينة كركوك).

الكلمات الدالة: مكب النفايات، المتوسط المرجح، المعايير المتعددة، نظم المعلومات الجغرافية.

1.INTRODUCTION

Solid waste management remains a critical global challenge for urban leaders and municipalities [1-3]. Municipal Solid Waste (MSW) significantly impacts the environment, necessitating efficient and sustainable management strategies [4-6]. In Iraq, the waste management system lacks regulation, posing unique challenges in dealing with heterogeneous data, criteria selection, and modeling for decision-making in waste management [7-8]. The increasing population, rising living costs, and continuous instability due to sectarian conflicts exacerbate Iraq's solid waste management issues [9]. Furthermore, the traditional methods of waste management in Iraqi cities, particularly landfilling, are inadequate for addressing the complexities of urban environments [2, 10]. In Kirkuk, for example, the current waste disposal practices are unsystematic and have led to environmental degradation, health risks, and inefficient resource utilization [11, 12]. The lack of a structured landfill site selection process impedes the city's ability to effectively manage waste, resulting in overabundant disposal facilities that contribute to air pollution, soil and water contamination, and the spread of disease vectors. The most important parameters for landfill site selection include population, groundwater table, land use/land cover, area slope, drainage density, soil type, lineament density, geomorphology, and geology [4, 13, 14]. Integrating Geographic Information System (GIS) technology with Multicriteria Decision Analysis (MCDA) methods is suggested to enhance landfill site selection [15-17]. Al-Mohammed et al. [18] highlighted Iraq's insufficient waste management system and underlined the importance of garbage sorting, recycling, and modernization. Awaz [19] evaluated the leachate and groundwater quality at the Kirkuk sanitary landfill, finding possible groundwater contamination hazards. Mitab et al. [20], Manguri and Hamza [21], and Othman et al. [22] used GIS and MCDA methods, such as AHP and Technique for Order Performance by Similarity to an Ideal Solution (TOPSIS), to identify suitable landfill sites in different parts of Iraq, considering factors, such as proximity to villages, wells, rivers, and land use patterns. Alkaradaghi et al. [23] used environmental maps, expert opinions, and MCDA to identify appropriate landfill sites in Sulaymaniyah, considering socioeconomic, accessibility, infrastructural, morphological, and hydrological variables. Aziz [24] investigated the residential solid waste generation rate in Erbil City, emphasizing the effects of population expansion, lifestyle changes, and seasonal fluctuations. Several studies, including Alanbari et al. [25], used GIS and MCDA to select landfill sites in different regions of Iraq, considering criteria such as urban centers, land use, airports, pipelines, power lines, railways, roads, slopes, surface water, industrial areas, and soil types. Furthermore, Alkhuzaie and Janna [26] and Alzamli et al. [27] used GIS, AHP, and fuzzy logic to select appropriate landfill sites in Al-Diwaniyah and Nasiriyah, respectively, considering factors such as groundwater depth, city centers, rivers, elevation, wind, roads, and expert opinions. The present paper proposes a systematic approach to address the challenges of landfill site selection in Kirkuk City. The systematic approach was used to identify the available lands for construction landfill locations, select suitable lands as typical sites, and address the challenges of landfill site selection in Kirkuk City.

2.METHODS AND MATERIALS

2.1.Study Area

Kirkuk is a city in the northwestern region of Iraq. It is bounded to the north by the Zagros Mountains, to the south by the Hamreen

Mountains, to the west by the lower Zab Mountains, and to the east by Al-Sulaymaniyah City. Kirkuk City is located at longitudes of (44° 00′ to 44° 50′ E) and latitudes of (35° 13′ to 36° 29′ N) [28]. This city covers an area of approximately 9,679 km². It is approximately 250 kilometers from Baghdad (Capital of Iraq). According to the Central Bureau of Statistics of the Ministry of Planning 2021, the population was predicted to be 1,726,409. Kirkuk is considered a significant city due to its wealth of oil and agricultural importance [29]. It is also regarded as a connecting point between the central and northern governorates mainly due to its geographical location. The topography of Kirkuk City varies, as it contains mountains and plain areas. The climate also varies between seasons, especially in terms of temperature and rainfall. Kirkuk City is rich in resources, especially oil, in addition to agricultural production in the region [30]. Figure 1 illustrates the study area involving Kirkuk City, Taza District, and Laylan District.

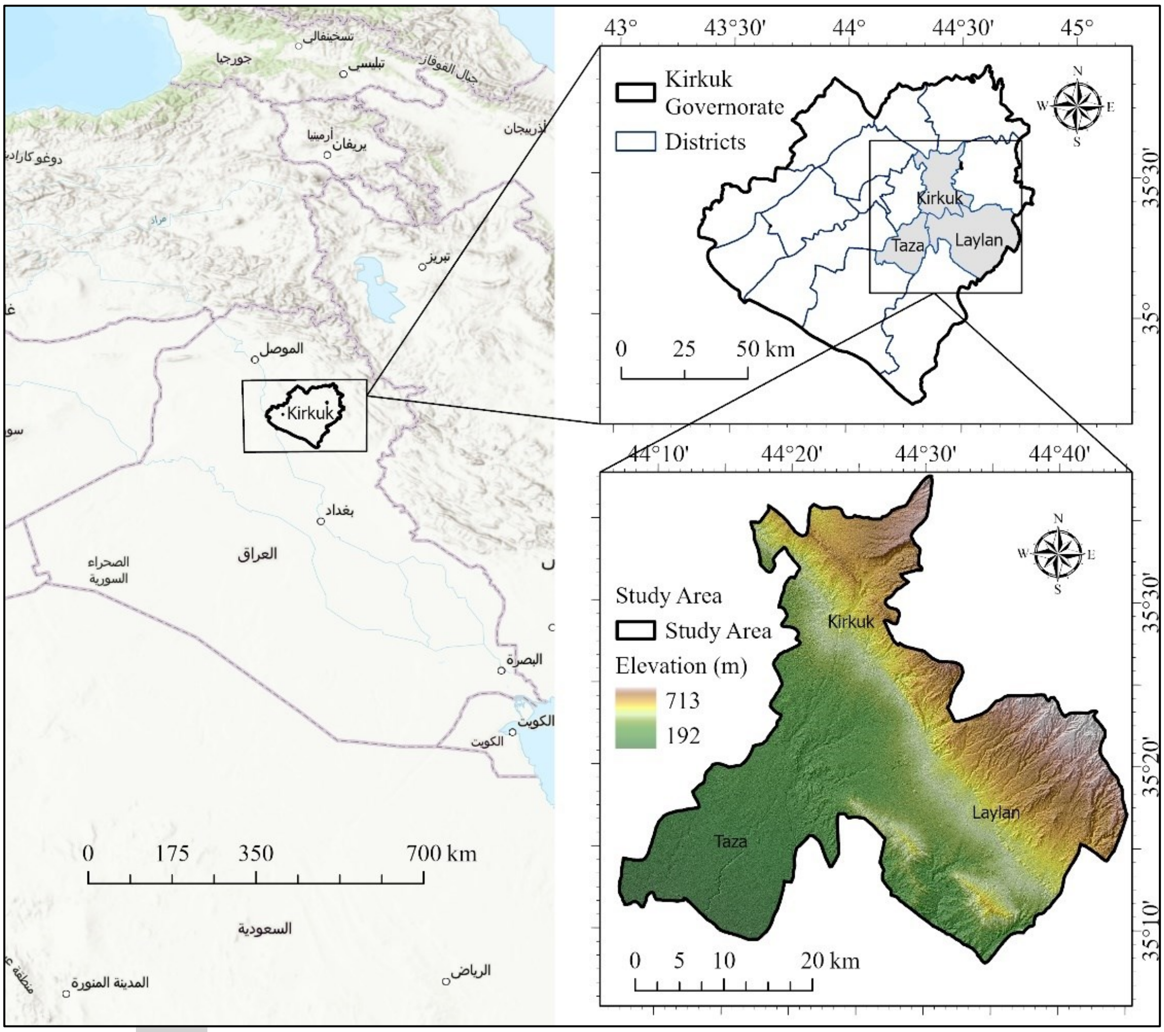


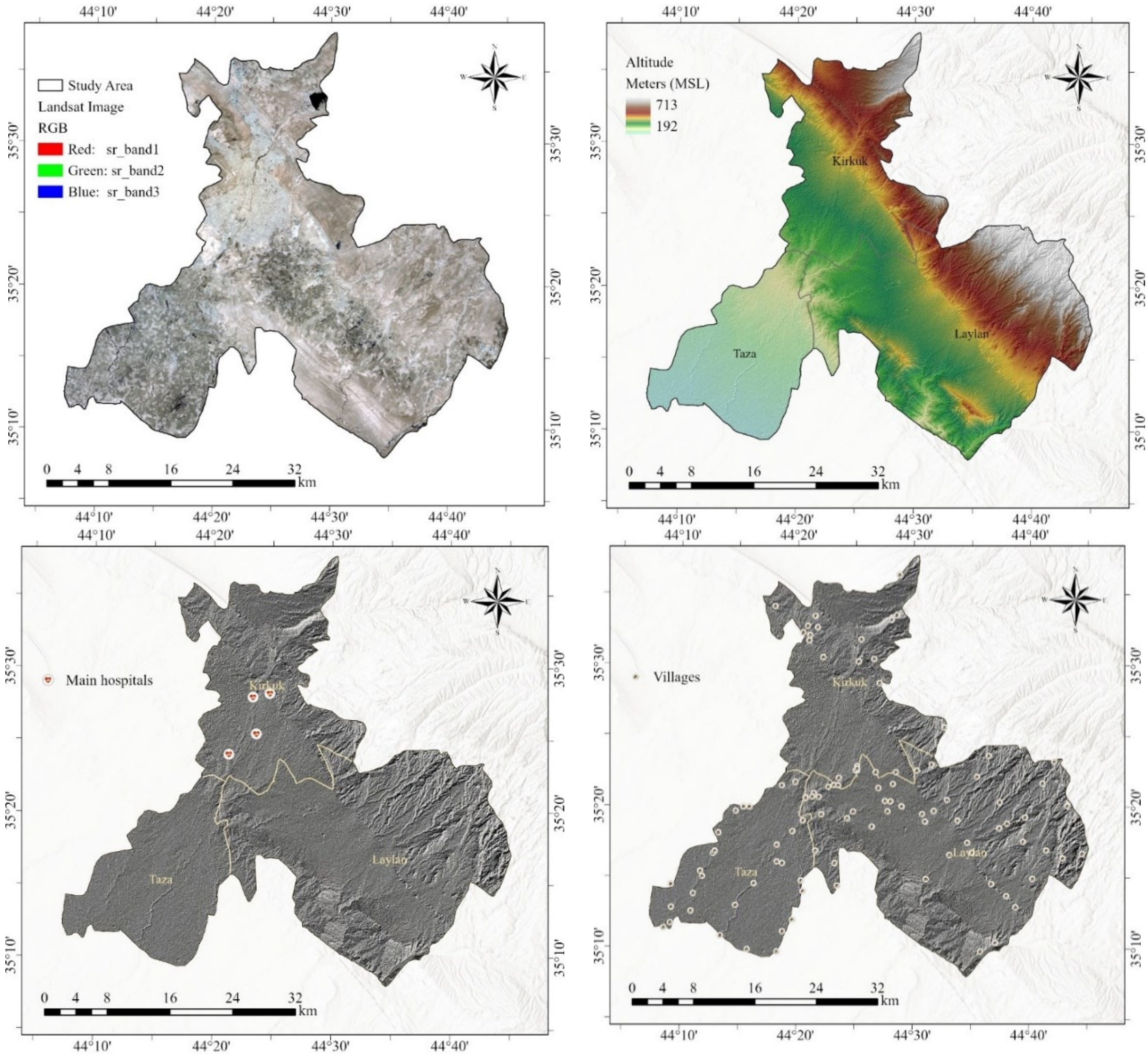
Fig. 1 The Study Area Map (Kirkuk City, Laylan District, and Taza District).

2.2.Data Used

Several datasets were used in this study to extract important factors to achieve the research objectives. First, a satellite image was acquired from Landsat 8 for 2023 that covers the study area to establish a land, subsequently extracting urban areas and water bodies [31]. A Digital Elevation Model (DEM) was obtained from ASTER GDEM to create the slope criteria. On the other hand, vector layers obtained from the Urban Planning Department of Kirkuk, including major roads, main hospitals, village locations, electrical transmission lines, and oil pipes, were used as factors to identify available land for landfill sites. Information on groundwater wells in the study area, with information about the stable water level, was obtained by the Inverse Distance Weighted (IDW) interpolation method [32]. IDW interpolation is ideal for interpolating stable groundwater levels from sample points into a raster map because it uses the spatial autocorrelation principle, preserves measured values at sample locations, produces smooth surfaces that reflect gradual changes in groundwater levels, and is computationally efficient. Furthermore, IDW's simplicity, intuitiveness, and emphasis on local impacts make it an acceptable choice when groundwater levels change due to geology and land use. A geological map from the Iraqi Geological Survey was used to construct a map of the soil type in the study area via the digitization technique. Table 1 shows the variable data and their types, specifications, and sources. The maps of these datasets are shown in Fig. 2.

Table 1 List of Datasets Used in the Present Work.

Data	Type	Source	Specifications
Landsat – 8 OLI	Satellite image (Raster)	USGS (https://earthexplorer.usgs.gov/)	Date Acquired = 2023/09/23 Cloud cover = 0% WRS Path/Row = 169/35
DEM	Raster	ASTER GDEM (https://gdemdl.aster.jspacesystems.or.jp/)	
Main Hospitals	Vector	Urban Planning Department	Shapefile (points)
Villages	Vector	Urban Planning Department	Shapefile (points)
Main Roads	Vector	Urban Planning Department	Shapefile (line)
Electrical Transmission Lines	Vector	Urban Planning Department	Shapefile (line)
Oil Pipes	Vector	Urban Planning Department	Shapefile (line)
Groundwater Wells	Vector	General Commission for Groundwater - Kirkuk Branch	Excel sheet updates by the hydrological section
Geological Map	Raster	Iraqi Geological Survey	Raster map with scale 1:250000



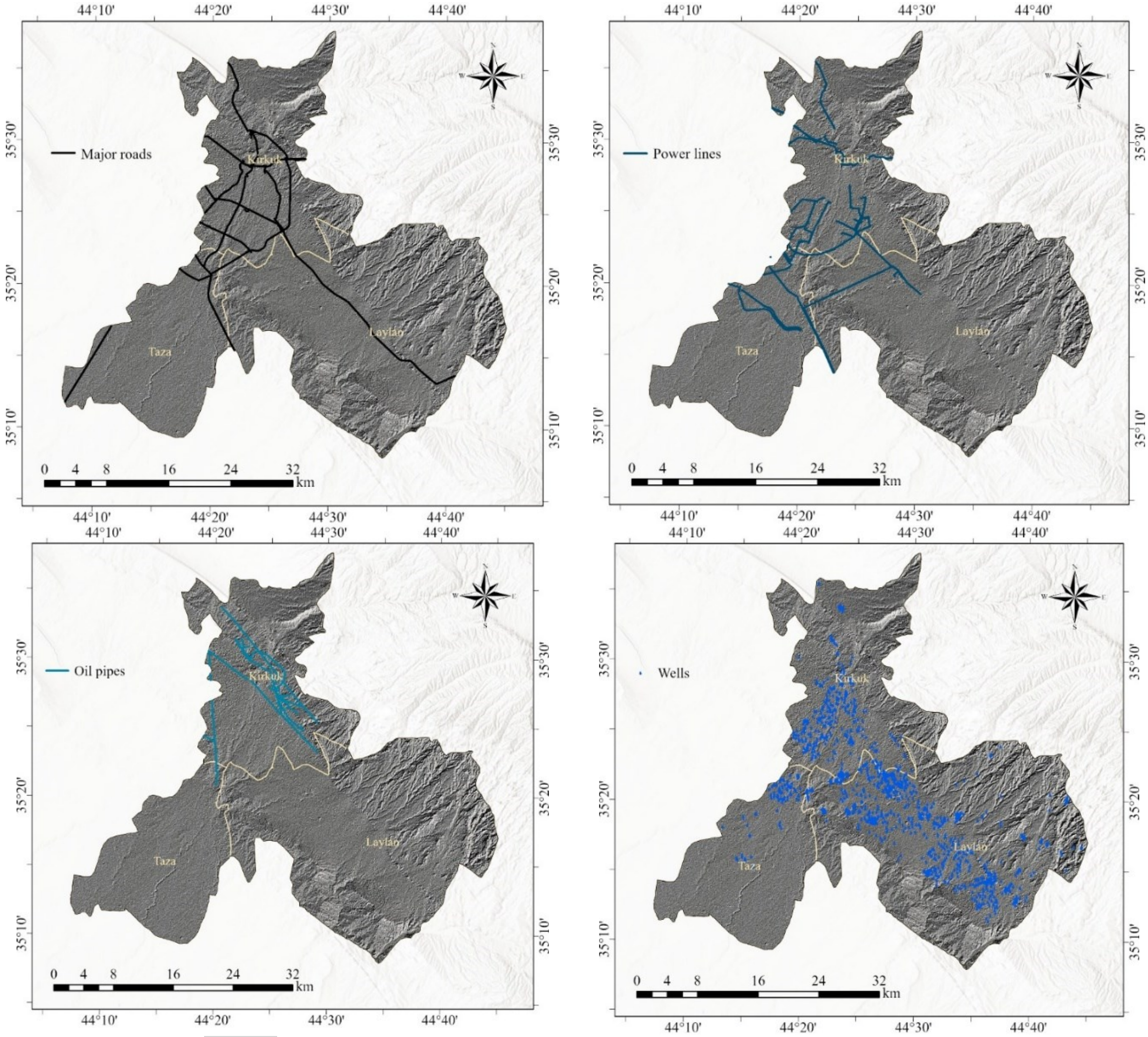


Fig. 2 Maps Presenting the Main Datasets Used in the Research.

2.3.Summary Statistics of the Data

The overall statistics of the vector data reflecting different aspects within the three districts of Kirkuk, Laylan, and Taza are shown in Table 2. The data makes it possible to compare the three districts quantitatively [33]. In particular, the dataset reveals that the Kirkuk district has major hospitals (4), along with a modest number of villages (21) and wells (385). Out of the three districts, it possesses the longest total length of major highways (111,107.59 meters), power lines (211,883.21 meters), and oil pipes (100,104.43 meters). Conversely, the Laylan district lacks a primary hospital while having the highest number of wells (1,033) and villages (53). It lacks oil pipelines and has a comparatively shorter total length of power lines (57,215.24 meters) and main highways (33,651.21 meters). Similar to Laylan, the Taza district lacks major hospitals and has the fewest wells (142) and villages (23), a total length of 31,840.64 meters for major roads, and 55,950.58 meters for electricity lines. However, Taza has a far shorter total length of 3,288.02 meters for oil pipes than Laylan. The three factors, altitude, slope, and groundwater stable level, across Laylan, Taza, and Kirkuk districts are summarized statistically in Table 3. The table summarizes statistics for every factor, including the values of the lowest, maximum, range, mean, standard deviation, median, and 90th percentile. The height raster data illustrates the diversity in elevation between the districts; Taza has the smallest range (112 meters) and the lowest minimum altitude (192 meters), whereas Laylan has the largest range (473 meters) and the highest maximum altitude (713 meters). The maximum slope (35.64 degrees) and largest range (35.64 degrees) in Laylan and the lowest maximum slope (19.53 degrees) and smallest range (19.53 degrees) in Taza are the two most extreme terrain steepness values found in the slope raster data. With Laylan having the highest maximum stable level (604.60 meters) and the widest range (522.43 meters) and Taza having the lowest minimum stable level (64.40 meters) and the smallest range (252.90 meters), the groundwater stable level raster data illustrates the depth of the groundwater table.

Table 2 Summary Statistics of the Vector Data for Each District within the Study Area.

District	Wells (number)	Main Hospitals (number)	Villages (number)	Major Roads (total length, meters)	Power Lines (total length, meters)	Oil Pipes (total length, meters)
Kirkuk	385	4	21	111107.59	211883.21	100104.43
Laylan	1033	0	53	33651.21	57215.24	0
Taza	142	0	23	31840.64	55950.58	3288.02

Table 3 Summary Statistics of the Raster Data for the Study Area.

Factor	District	Min.	Max.	Range	Mean	Std.	Median	PCT90
Altitude (m)	Laylan	240.00	713.00	473.00	388.44	95.67	351.00	541.00
	Taza	192.00	304.00	112.00	229.39	19.11	225.00	256.00
	Kirkuk	275.00	632.00	357.00	385.05	70.12	371.00	487.00
Slope (degrees)	Laylan	0.00	35.64	35.64	3.86	2.98	3.24	7.43
	Taza	0.00	19.53	19.53	2.11	1.49	2.29	4.04
	Kirkuk	0.00	34.23	34.23	3.60	2.52	2.92	6.84
Groundwater Stable Level (m)	Laylan	82.17	604.60	522.43	330.08	92.91	304.59	481.48
	Taza	64.40	317.30	252.90	189.74	25.74	190.02	209.97
	Kirkuk	101.53	395.44	293.91	274.40	29.51	280.87	303.94

2.4.Methodology

2.4.1.Overview

Figure 3 depicts the proposed methodology to determine the suitability of landfill locations. The overall methodology in the present study is divided into two sections. The first section specifies the method of determining the available lands for constructing new landfills in the study area [34]. The second section describes assessing the site suitability for landfill construction based on the weighting process using the weighted average method for applying MCDA [16] and determining the best landfill sites in the study area. ASTER DEM, geological maps, groundwater well data, village sites, Landsat images, infrastructure networks (roads, oil pipelines, electric transmission lines), and hospital locations are just a few of the many data sources included in the process [29]. The Landsat image undergoes preprocessing procedures, such as atmospheric and radiometric calibrations. Different spatial analysis approaches are used to determine the slope, soil type, and stable groundwater level parameters: 3D surface analysis, digitizing, and IDW interpolation. The weighted average method is used to integrate these variables and evaluate the viability of the property when choosing a dump site. Urban areas and water bodies are extracted from the Landsat image by applying Random Forest Classification, yielding land cover classes. These classifications are then assessed for correctness. After defining a region of Interest (AOI), a limited region is determined by considering water bodies, urban areas, and other limitation factors. After applying buffering to the restricted area, the buffered region is used to evaluate the availability of land for possible landfill site selection, considering geological, infrastructure, and environmental aspects.

2.4.2.Establishing Land Availability Factors

The various factors used to find land for landfill construction are very important and chosen according to certain considerations [35]. Engineering, environmental, and economic factors are among the essential factors for finding available land for constructing a landfill in Kirkuk and its suburbs. Land cover types, including urban areas and water bodies, are among the factors used in this research [30]. Other significant factors in this study are main roads, main hospitals, village locations within the study area, electricity transmission lines, and oil pipelines. Table 4 shows the main factors for defining available land with buffers around some of them.

2.4.3.Establishing Land Suitability Criteria

The landfill site selection process for the present study involved integrating multiple criteria, including slope, groundwater stability level, and soil type. The criteria are evaluated separately and then combined to obtain a comprehensive assessment of potential areas for landfill construction [36-37]. The slope criterion is utilized to evaluate the suitable terrain for landfill construction, and it reflects the degree to which the ground is steep. Slopes of a few degrees are preferable for constructing many projects, including landfilling. The greater the degree of slope is, the less preferable it is because it will require a high cost. Slopes are derived from several sources. In this study, the DEM was used to determine the slope of the ground in the study area through spatial analysis via GIS. The second criterion is the stable groundwater level, an important criterion for evaluating the suitability of available spaces for constructing landfills [38]. Since the stable groundwater level is high, it is not suitable for constructing landfills; however, it is preferable to construct landfills in areas where the stable groundwater level is low. A map of the stable groundwater level was prepared using IDW interpolation and based on detailed data for the wells obtained from the General Commission for Groundwater, Kirkuk Branch. The soil type was the final basic criterion for finding this study's most suitable landfill site [39]. There are many sources for preparing soil maps, including laboratory surveys, soil geotechnical reports, and soil maps, which were relied upon in this study where a digital map was created in GIS for the geological map of the region, which was obtained from the Iraqi Geological Survey [40]. The type of soil is important for determining the suitability of the available spaces for constructing landfills [41], as the low permeability and instability of the soil lead to the impossibility of constructing landfills. On the other hand, the permeability of the soil, such as sandy soil and gravel, is preferred for constructing landfills. Figure 4 shows the maps of the three criteria in the study area.

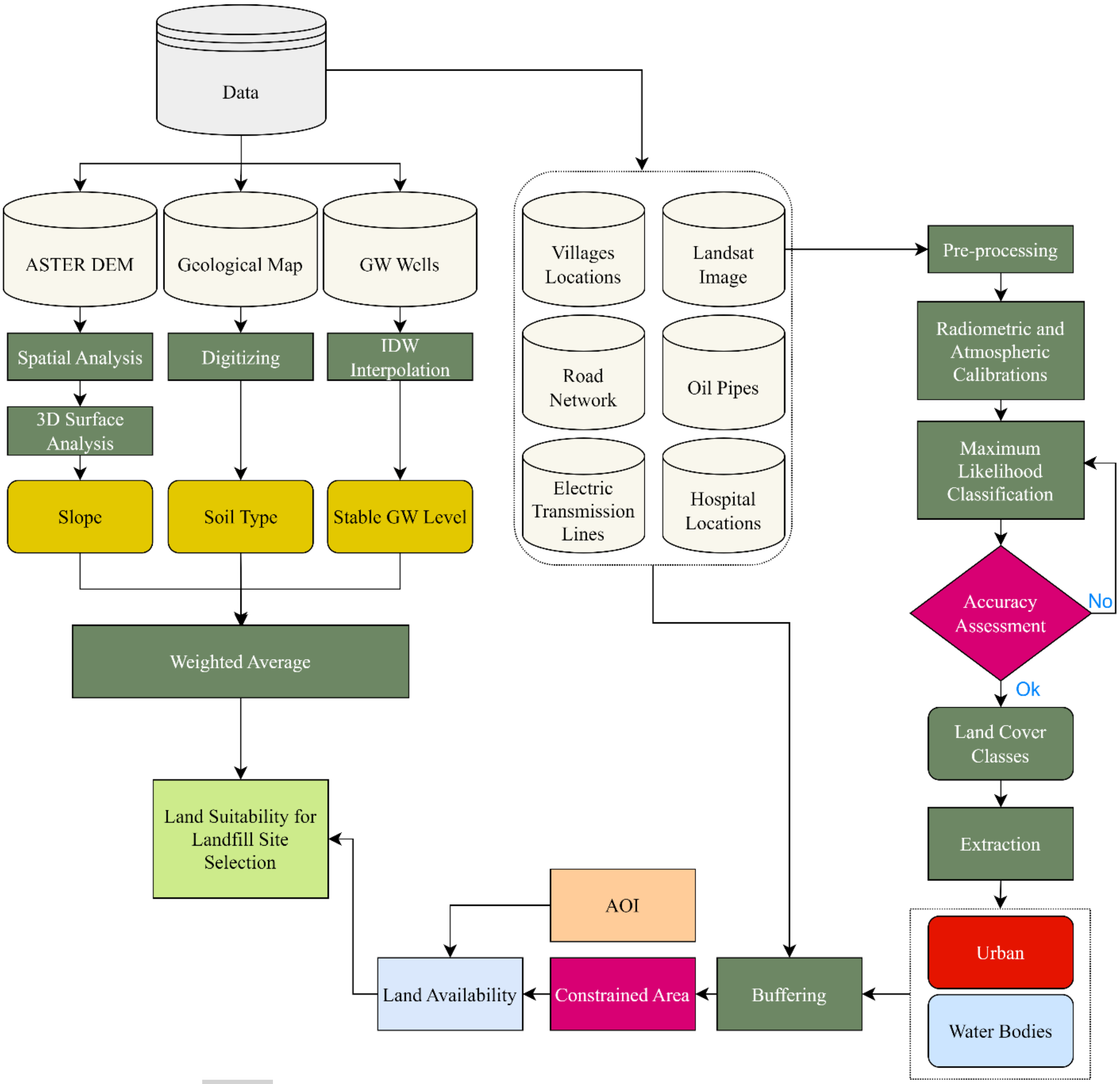


Fig. 3 The Flowchart of the Overall Methodology of this Research.

Table 4 The Main Factors of Landfill Land Availability and their Settings.

Factors	Distance from landfill (m)
Urban	1000
Water Bodies	500
Villages	1000
Main roads	500
Oil pipes	250
Main hospitals	1000
Electrical Transmission Lines	200

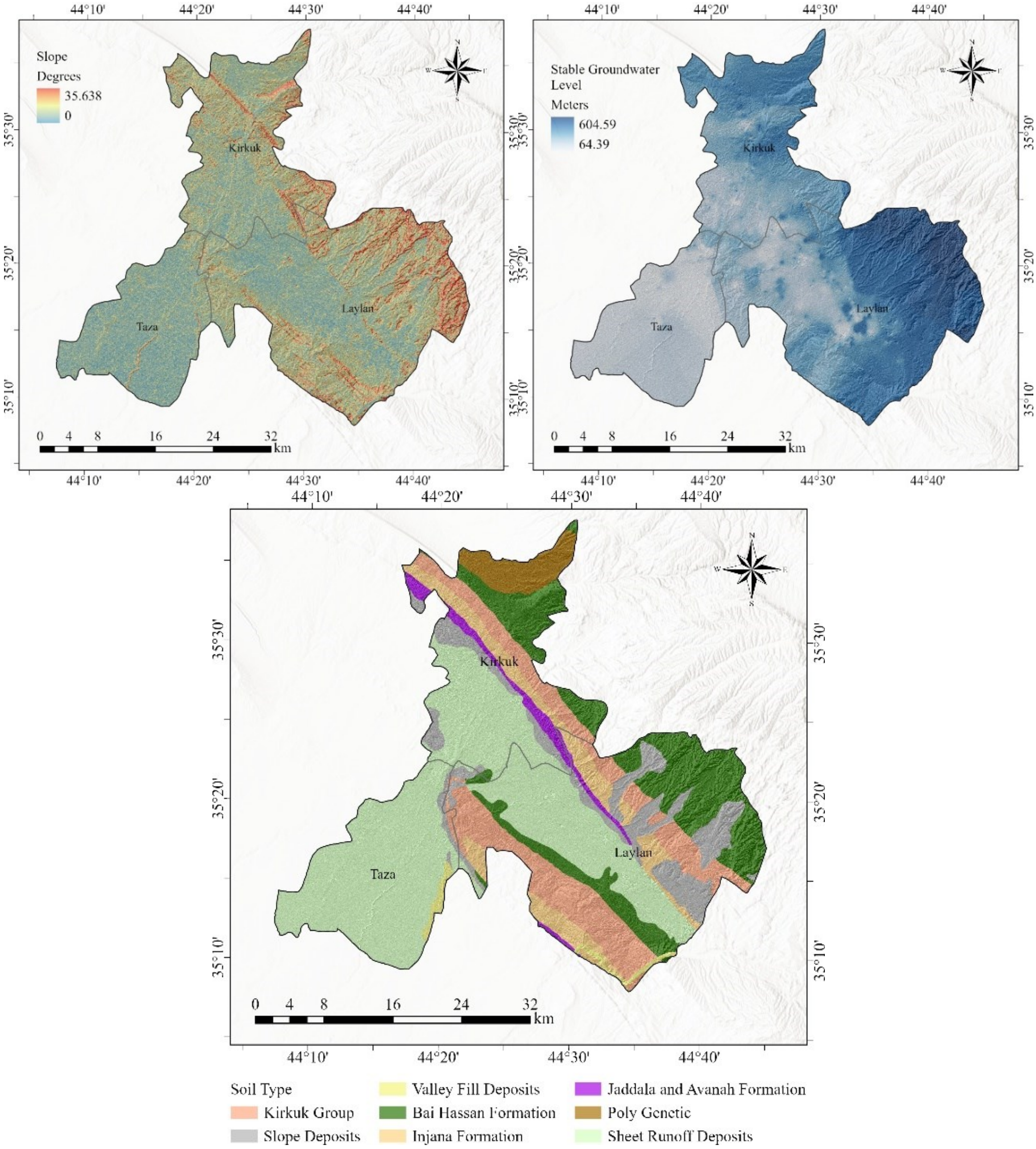


Fig. 4 Maps of the Landfill Suitability Criteria Used in this Work.

2.4.4. Weighted Average for Evaluating Landfill Suitability Criteria

The weighted average method is a mathematical approach used to calculate a combined score or value by considering the relative importance or weight of different factors or criteria [42]. This method is commonly employed in decision-making processes where multiple criteria must be considered, and each criterion may have varying degrees of importance [43]. The weighted average (x_i) can be calculated using the following formula:

$$\bar{x} = \frac{\sum_{i=1}^{n} W_i \times x_i}{\sum_{i=1}^{n} W_i} \qquad (1)$$

where:

- W_i is the weight assigned to criterion i.
- x_i is the value or score of criterion i.
- n is the total number of criteria considered.

This formula represents the sum of the products of each criterion's weight (W_i) and its corresponding value (x_i), divided by the sum of all the weights. In other words, it calculates the average value of the criteria, where each criterion's contribution is weighted by its relative importance.

2.4.5. Criteria Weights

It is important to assign weights to the main criteria and sub-criteria when choosing the most suitable place for landfilling. In this study, the weighted average method was used to weigh the main and sub-criteria according to expert opinion. To ensure a thorough and robust review of the site selection criteria, this study interviewed six subject matter experts from various but related domains. The panel included eminent professors from local institutions, each with more than a decade of expertise in their respective fields. The specialists included a professor of environmental engineering, an assistant professor of geotechnical engineering, a Ph.D.-holding hydrogeologist, a geomatics expert, an urban planning professor, and a GIS/remote sensing specialist with a PhD. These specialists were carefully chosen for their extensive knowledge and practical experience, ensuring that the review process was influenced by a comprehensive viewpoint. During the interviews, the experts used the AHP approach to compare the major and sub-criteria pairwise. In accordance with best standards, the consistency ratio for paired comparisons was kept below the suggested level of 10%, assuring the reliability and validity of the evaluation results. The main criteria in this study are slope, groundwater stability level, and soil type. The sub-criteria of slope criteria are classified into four classes according to the degree of slope. The classes of slope are (0 – 3), (3 – 6), (6 – 9), and (9 – 35.638). Five categories represented the sub-criteria for stable groundwater levels: (0.388 – 112 m), (113 – 224 m), (225 – 236 m), (237 – 448 m), and (449 – 560 m). The stable level of groundwater is meters above the mean sea level. The sub-criteria for soil types were classified into eight categories according to their distribution in the study area: Valley Fill Deposit, Sheet Runoff Deposit, Slope Deposit, Poly Genetic, Bai Hasan Formation, Kirkuk Group, Injana Formation, and Jaddala and Avana Formations [44]. Table 5 shows the process of weighting the main criteria to find the most suitable places for landfill construction. Tables 6, 7, and 8 show the weights of the sub-criteria for slope, stable groundwater level, and soil type, respectively. As the outcomes of the weighted average process, the criterion weights were entered into the attribute tables of the criteria in GIS, and spatial maps were then exported. Figure 5 presents the weights of the slope, stable groundwater level, and soil type.

Table 5 Weights of the Main Landfill Suitability Criteria.

Criteria	Grade	Weights
Soil	92	0.356
Groundwater stable level	86	0.333
Slope	80	0.310
Sum	258	1

Table 6 Weights of the Slope Sub-Criteria.

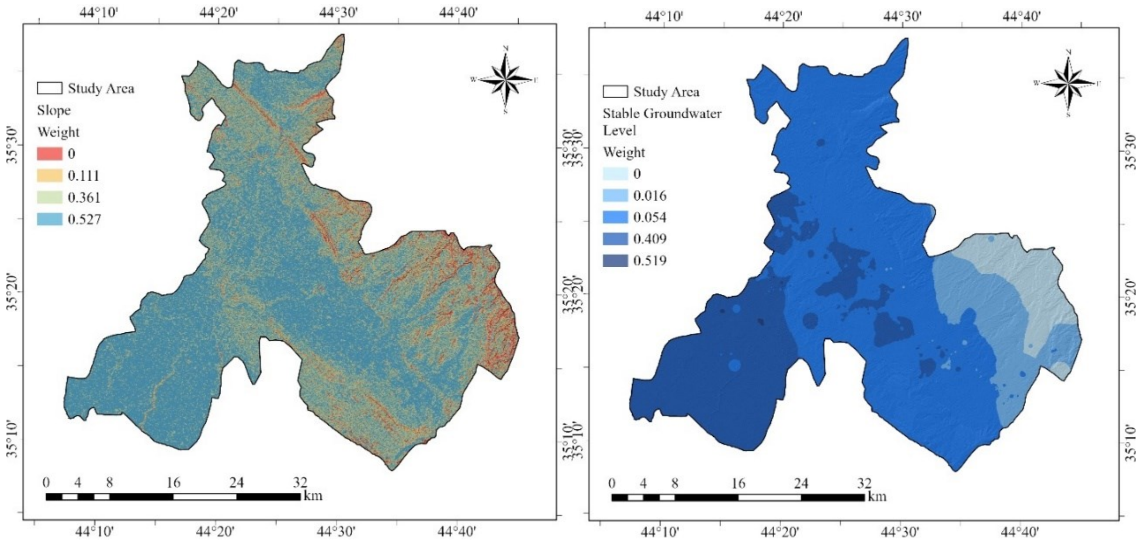
Criteria	Grade	Weights
0 – 3	95	0.527
3 – 6	65	0.361
6 – 9	20	0.111
9 – 35.638	0	0
Sum	180	1

Table 7 Weights of the Groundwater Stable Level Sub-Criteria.

Criteria	Grade	Weights
0.388 - 112	95	0.519
113 - 224	75	0.409
225 - 336	10	0.054
337 - 448	3	0.016
449 - 560	0	0
Sum	183	1

Table 8 Weights of the Soil Type Sub-Criteria.

Criteria	Grade	Weights
Injana Formation	66	0.140
Kirkuk group	15	0.031
Valley Fill Deposits	50	0.106
Sheet Runoff Deposits	95	0.202
Bai Hassan Formation	35	0.074
Slope Deposits	98	0.208
Poly Genetic	95	0.202
Jaddala and Avanah Formation	15	0.031
Sum	469	1



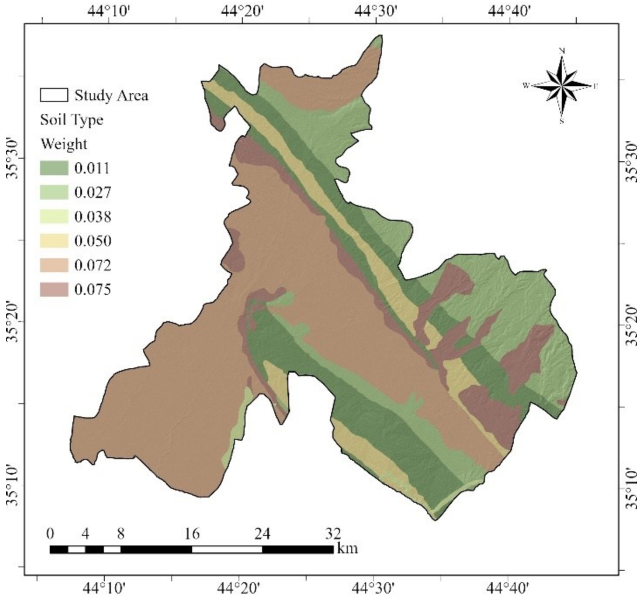


Fig. 5 Maps of the Three Landfill Suitability Criteria Representing the Weights of Each Criterion.

2.5. Software and Tools

In this research, a set of software tools was employed to facilitate spatial data management, analysis, and visualization. ArcGIS Pro 3.1.0, a powerful GIS software, was utilized for spatial data management, analysis, and mapping tasks. Python, a programming language, was leveraged for statistical analysis and land cover classification, enabling robust data processing and modeling capabilities. Additionally, ENVI, a specialized software for remote sensing applications, was employed for preprocessing satellite imagery, including radiometric and atmospheric corrections. All spatial data and maps presented in this research were produced using the Universal Transverse Mercator (UTM) Zone 38N coordinate system, ensuring consistent spatial referencing and accurate representation of geographic features.

3. RESULTS AND DISCUSSION

3.1. Results of Statistical Analysis of the Landfill Suitability Criteria

The correlation matrix, which displays the degree of linear link between the three factors—slope, groundwater stable level, and soil type, is shown in Table 9. The matrix has values between -1 and 1, where 1 denotes a perfect positive correlation, -1 is a perfect negative correlation, and 0 is no connection. According to the table, there is a moderately positive correlation (0.421) between soil type and groundwater stable level, a moderately positive correlation (0.373) between slope and groundwater stable level, and a moderately positive correlation (0.336) between soil type and slope. These positive associations imply that particular soil types are more frequently found in places with steeper slopes and greater groundwater levels, which may impact the suitability evaluation.

The global Moran's Index analysis, which gauges the factors' spatial autocorrelation, summarized the results in Table 10. Clustered patterns are indicated by a positive Moran's Index value, while scattered patterns are indicated by a negative value. The values of each factor's p-value, variance, z-score (a statistical significance indicator), and predicted index under the null hypothesis of no spatial autocorrelation are shown in Table 10. According to the p-value, the pattern field analyzes the data. With a p-value of 0.172, the pattern for soil type insignificantly differed from random. Nonetheless, the p-values were less than 0.01, showing a substantial possibility (less than 1% chance) that the observed clustering patterns were not random for slope and groundwater stable levels. These findings imply that groundwater stable level and slope show notable regional clustering, which may impact the selection of possible landfill sites and the appropriateness evaluation.

Table 9 The Correlation Matrix of the Main Factors of Landfill Suitability Assessment.

	Soil Type	Groundwater Stable Level	Slope
Soil Type	1	0.421	0.336
Groundwater Stable Level	0.421	1	0.373
Slope	0.336	0.373	1

Table 10 The Summary Results of the Global Moran's Index for the Main Factors of Landfill Suitability Assessment.

Criteria	Moran's Index	Expected Index	Variance	z-score	p-value	Pattern
Soil Type	-0.409	-0.142	0.038	-1.365	0.172	The pattern appears to be insignificantly different than random.
Slope	0.196	-0.001	0.00096	6.365	0.000	There is a less than 1% possibility that this clustered pattern could result from random chance.
Groundwater Stable Level	0.970	0.001	0.00096	31.250	0.000	There is a less than 1% possibility that this clustered pattern could result from random chance.

3.2. *Classification Results*

Figure 6 shows the land cover classes of the study area using the random forest classification method. The land cover is classified into four main classes, represented by yellow barren areas that cover most of the study area, especially the southeastern part. The red represents the urban areas, which are mainly in the center of the study area and inside the city of Kirkuk and other districts of Laylan and Taza. The green areas are the denser vegetation classes in the southwestern part of the study area. Finally, the blue areas, which are water bodies in the northeastern study area (Khasa chai) and small parts with line patterns (streams), are in the middle–southern part of the study area. Figure 7 indicates the area and proportions of the land cover for the study. Based on the random forest classification method, according to training and testing, the overall accuracy was 95.525%, and the kappa coefficient was 0.934.

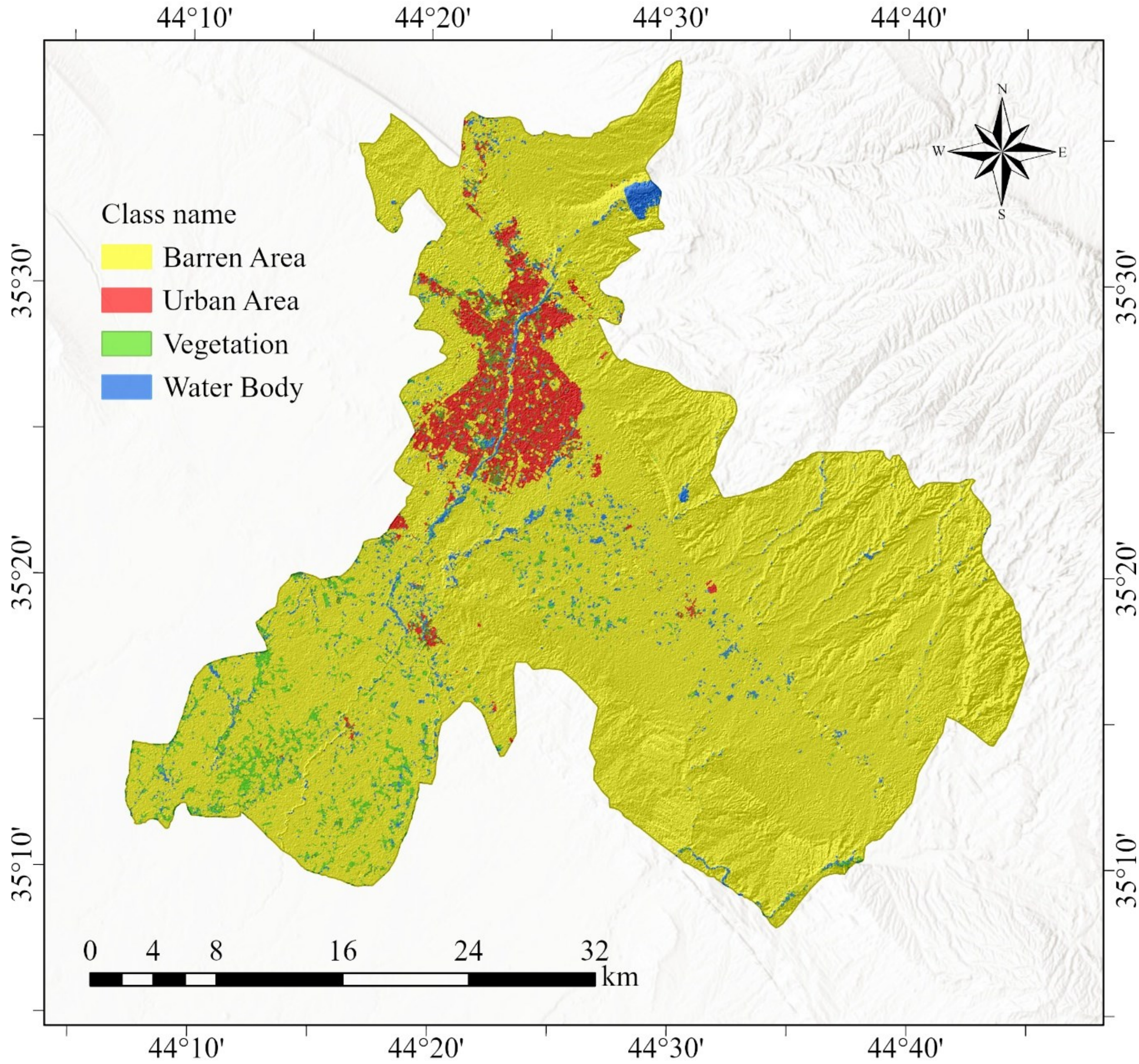


Fig. 6 Land Cover Map of the Study Area Produced by Random Forest Classification.

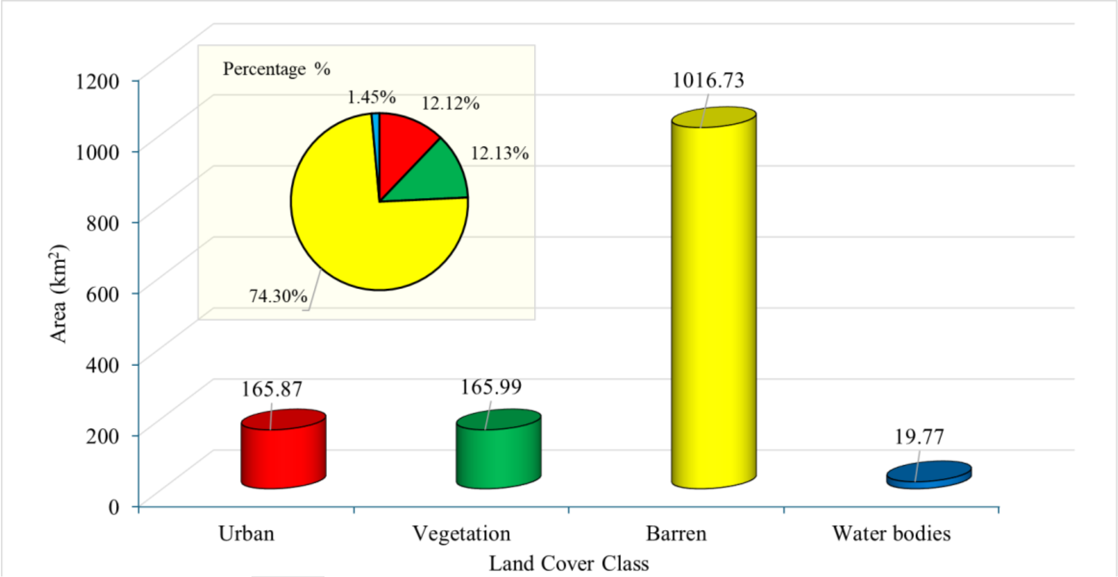


Fig. 7 Areas and Percentages of Land Cover Classes.

3.3.Land Availability Results

Figure 8 represents the available and unwanted lands for constructing landfills in Kirkuk and its outskirts, represented by the Laylan and Taza districts. The available lands are represented by green leaves, with an area of 613.56 km^2, which is 44.84% of the study area. The lands available for landfill construction are distributed in the study area's northeast, southeast, and southwest areas, so large areas prevail in the southwest areas of the study area within the Taza district. The unwanted areas dominate the study area to a considerable extent, with an area of 754.78 km^2, representing 55.16% of the study area, and are represented by olivine yellow, which represents the merging of the factors that were chosen along with buffers of most of them. In practice, before starting to choose the most suitable places, the southern regions of the study area are an ideal location for constructing landfills due to the prevailing wind direction from the northwest to southeast of the study area; therefore, burning waste, which represents environmental pollution, does not affect the city of Kirkuk.

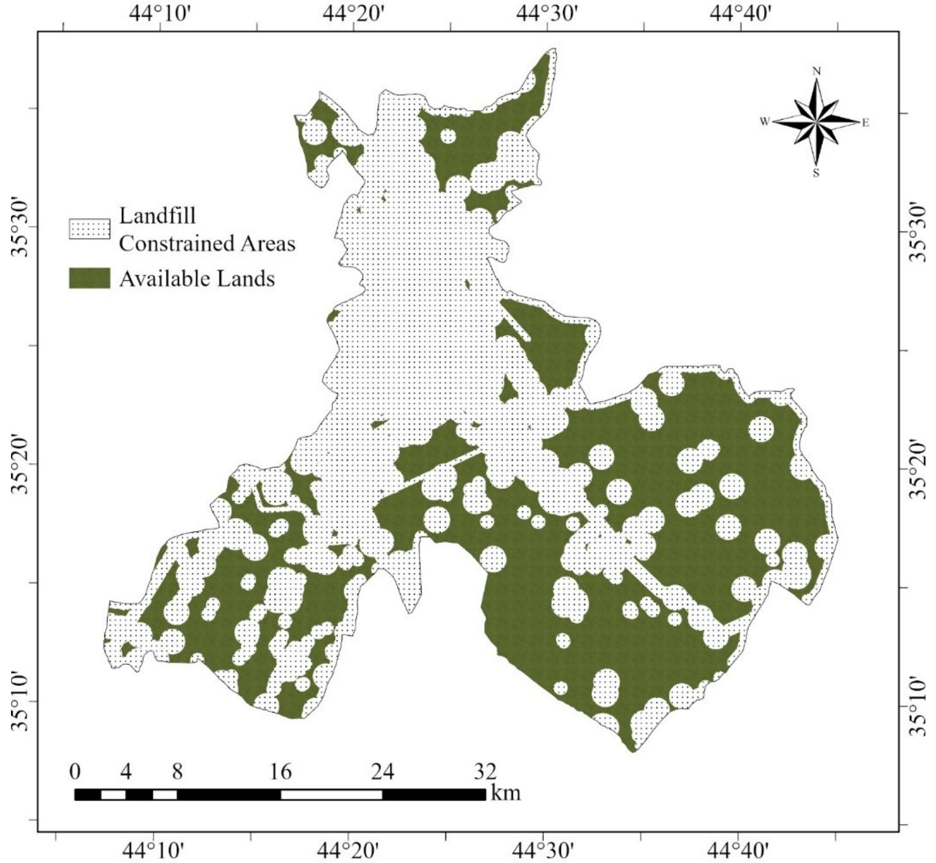


Fig. 8 Available Land Used to Construct Landfill Locations Across the Study Area.

3.4.Land Suitability Results

According to the weights of the slope criteria, groundwater level, and soil types that cover the study area, the suitable sites for constructing a landfill are classified into five levels: very high, high, medium, low, and very low suitability. Figure 9 (a) presents the map of the landfill site suitability as generated by the weighted sum overlaying the suitability criteria. Figure 9 (b) shows the suitability map for the available lands, removing the lands restricted to constructing landfills. To further improve the practicability of the site suitability, a land use compatibility map was developed based on the land use map of the study area. Urban and water areas were combined into a single class and considered incompatible for landfill construction. On the other hand, the vegetation cover class was considered moderately compatible, while the barren area class was considered highly compatible (Fig. 9 (c)). The final landfill site suitability is constructed by combining the suitability of the available lands (Fig. 9 (b)) with the land use compatibility. Figure 9 (d) presents the final landfill site suitability map of the study area. According to the final suitability map, the most suitable places are in blue and are distributed more in the southwest of the study area, i.e., within the Taza district. The area of the very highly suitable areas is estimated to be 153.94 km². The high and moderately suitable places are marked in light blue and light green and are distributed in the northeast, central part of the study area, with an estimated area of 187.69 km² and 189.75 km², respectively. The low and very low suitability areas are represented in yellow and red and are distributed in a few places east and southeast and a few parts northwest of the study area, with a combined area of 83.97 km². The spatial distribution of the highest places suitable for constructing landfills is considered very logical, as the most suitable type has larger areas, in addition to its distribution in the southwest of the study area, which is considered the most suitable in terms of wind direction. Table 11 presents the location information of four landfill sites selected based on the final landfill suitability map, considering the local knowledge of the study area, site characteristics, and area of the available lands. Overall, four sites were selected: two are within Laylan, and the other are in Taza and Kirkuk.

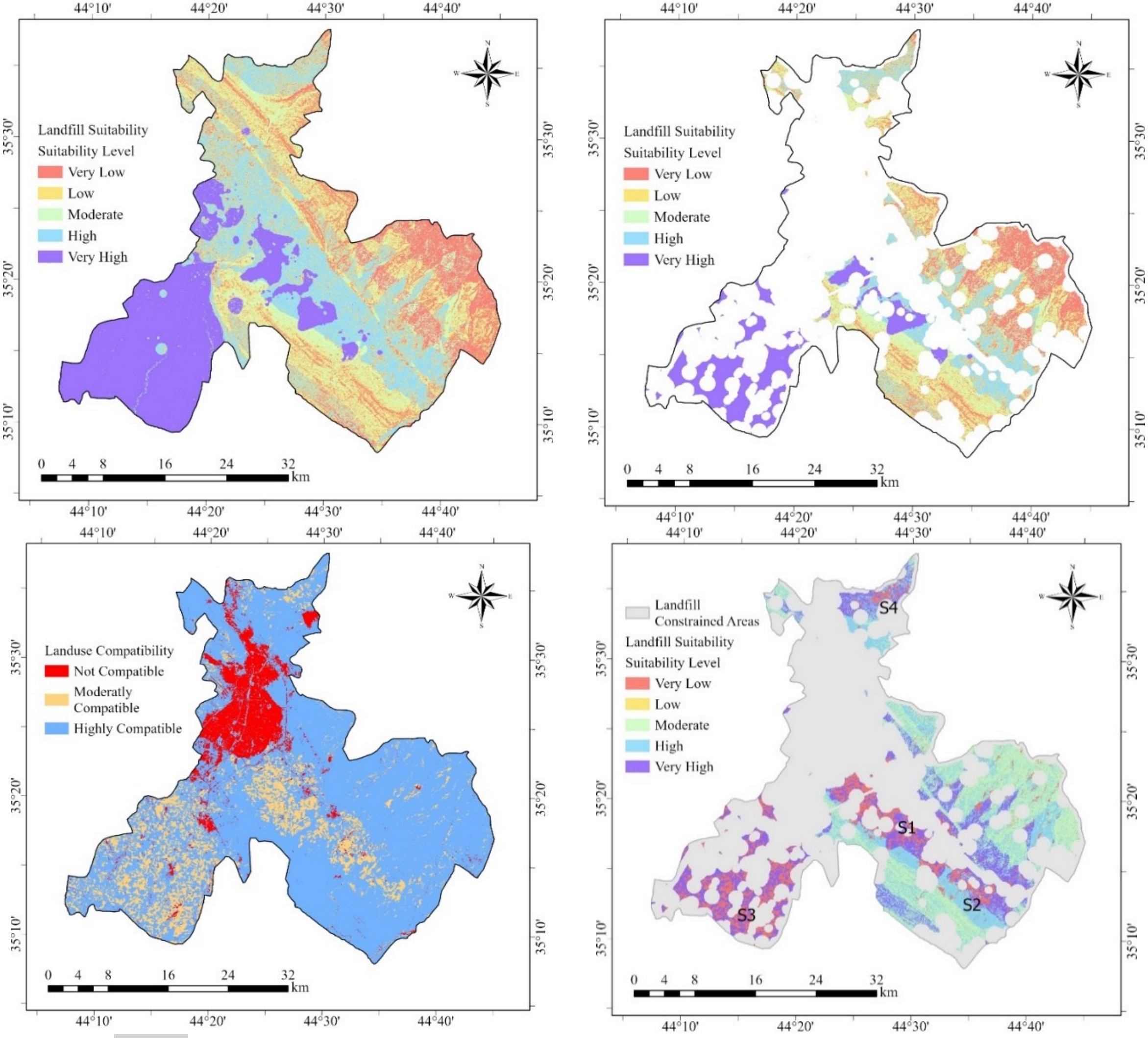


Fig. 9 Suitable Land for Constructing Landfill Locations Across the Study Area.

Table 11 Location Information of the Selected Specific Sites for Landfill Construction in the Study Area.

Name	UTM Z38 N Coordinates		Location
	E	N	
Site 1	454274.9	3904833	Laylan
Site 2	463162.2	3896117	Laylan
Site 3	432142.3	3895433	Taza
Site 4	452651.3	3938246	Kirkuk

4.CONCLUSIONS

The random forest classification method was used in this study to qualify the factors of urban areas and water bodies, unlike the other factors obtained from the Directorate of Urban Planning in Kirkuk. For exporting the main criteria, several methods were used, including digitization to produce a map of soil types, the IDW interpolation technique to produce a map of the stable groundwater level, and spatial analysis via GIS and reliance on DEM to produce a slope map of the study area. Determining landfill sites in the city of Kirkuk and its suburbs, Taza and Laylan, is of great importance in this study because it was based on a scientific and systematic method, the weighted average method. Finding the most suitable places for landfills allows decision-makers in the study area to develop landfill locations. The factors for finding available areas and the criteria for choosing the most suitable places for landfilling were fundamental in achieving logical and practical results. The available land for landfill construction was 613.56 km^2, distributed in the study area's northeast, southeast, and southwest areas. The medium suitability had an area of (189.75 km$^{2)}$, while the high and very high suitability areas covered 187.69 km^2 and 153.94 km^2, respectively. Subsequently, four specific sites (two in Laylan, one in Taza, and one in Kirkuk City) were selected as proposals for constructing new landfills in the area.

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