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Optimization of Municipal Solid Waste Landfill Site Selection by Geospatial Analysis in the Ranya District of Iraq

Shwana Braim Manguri*, Bashdar Omer, Awin Ahmed, Shad Hamad, Shawnm Mawlood, Abdulbast Majid
Civil Engineering Department, University of Raparin, Ranya, Sulaymaniyah, 46012, Iraq.

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ABSTRACT

Landfill siting is a major problem in solid waste management. Many aspects should be considered when selecting an appropriate site for a landfill in any particular region. In the current research, seventeen criteria were considered, including rivers, water bodies (lakes), geology, slope, elevation, power lines, groundwater depth, major district roads, archaeological sites, urban centers, infrastructure, villages, pipelines, quarrying, forests, aspect (wind), and agricultural areas. Several random open dump waste disposal sites are dispersed throughout the Ranya District, Iraq. This research employed the integration of a Geographic Information System (GIS) and Analytical Hierarchy Process (AHP) to identify the optimal sites for the establishment of sanitary landfills. The seventeen criteria were mapped and assigned sub-criteria within GIS software. Subsequently, the normalized weights from the AHP were identified for each measure to generate the final Land Suitability Index (LSI) map for the site. Consequently, approximately 0.34% of the entire study area, equivalent to roughly 2,396,000 square meters, is estimated to be suitable for locating a landfill. Additionally, the suitable sites were categorized into moderately suitable, suitable, and mostly suitable. The normalized weight analysis revealed that groundwater depth significantly influences the selection of the best landfill site

1. Introduction

Landfill site selection is a major environmental issue and a matter of great concern for countries and establishments. Exploring new solid waste disposal areas is time-consuming, especially when existing waste sites are filling up. For many years, the most common approach to solid waste disposal has been landfilling, as practiced by various communities [1–3]. The initial steps involve examining recycling, reuse, reduction, and thermal and biological treatment. After these processes, any remaining solid waste is deposited in designated waste dumping areas [4–8]. Sanitary landfills are a vital component of the global solid waste treatment system. Despite the fact that municipal solid waste management uses alternative methods of disposal, the dumping process has been observed to be a relatively low-cost and simple method of execution [9, 10]. Many

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*Corresponding author Tel.: +96 47 511299729
E-mail: shwana.manguri@uor.edu.krd
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factors should be considered in selecting a landfill, such as expanding urbanization, environmental policy, reduction of obtainable areas for landfills, settlement areas, rising social and political opposition, governmental economic situations, and the municipality's findings of the complicated task for city planners and local authorities [11–13].

A landfill is a final waste disposal control measure in or on land. However, there are different kinds of landfills: sanitary, industrial, and municipal solid waste landfills. A sanitary landfill refers to a specifically designated excavation that features a sealed foundation. Within this space, waste undergoes a compaction process to enhance its density and is methodically layered with cover material. Sanitary landfills are designed to safely contain waste, minimizing the environmental harm from trash and allowing for controlled decomposition. This study addresses this goal by creating a method to choose landfill sites in Ranya, Iraq, considering the environmental, social, and economic factors. By identifying local criteria and using a multi-criteria decision analysis, the study will rank potential sites while understanding their impact on nearby communities.

The study area was littered with open dumps, raising severe environmental, social, and economic concerns. Open dumpsites are a significant source of leachate, which can lead to groundwater contamination [14], emission of greenhouse gases and debris [15], as well as surface water pollution [16]. Currently, the focus worldwide is on sustainability and climate change; therefore, the use of open dumps needs to align with the increasing awareness of the public regarding environmental problems. Thus, upgrading or closing open dumps for many communities is a crucial issue. Upgrading open dumps is fundamental in reducing future public health and environmental impacts. Open dumps lack essential measures like waste segregation, compaction, and proper cover, which results in uncontrolled fires, attracts pests, and facilitates the spread of contaminants.

On the other hand, accurately applied technology can save time and costs on explorations, especially with the advancement in computation over the last two decades. Geographic Information System (GIS) software was used in this research to select the most suitable landfill site; it is designed to manipulate vast volumes of spatial data from various resources [17]. It is the best option for advanced site selection research because it efficiently stores, analyzes, and presents data in accordance with user-specified criteria. GIS has been widely used to facilitate and minimize the expenditure of the landfill site selection process [18–20]. GIS was combined with multiple criteria analysis for use with other siting techniques [21]. For evaluating a suitable siting, this technique was used for the entire study area based on the Land Suitability Index (LSI). GIS integration, validated by many researchers, enhances landfill site selection [18–20]. Furthermore, multiple criteria analysis with GIS, using spatial analytics for comprehensive evaluation, enhances traditional siting methods, reduces costs, and improves decision-making. Applying this integrated technique across the study area, guided by the LSI, allowed systematic comparison and ranking of potential sites. Aligned with contemporary practices, GIS and multiple criteria analysis provided a robust framework for sustainable urban planning and waste management [21].

Meanwhile, Saaty [22] introduced AHP, which is an approach to decision-making that can be employed to address and assist in decisions involving multiple objectives. It is used to prioritize potential landfill areas based on a wide range of criteria. The AHP method breaks down the problem into sub-problems, rendering them more easily comprehensible, open to subjective assessment, and convertible into numerical values [23–30]. Furthermore, it constructs a decision hierarchy by dividing a complex problem into a number of more straightforward problems [31]. Subsequently, a pairwise comparison matrix is created for each component within each level, allowing for their comparison and weighing against each other [32, 33].

The integration of AHP and GIS is a powerful tool for landfill siting, with researchers worldwide applying this approach over the last decades. Numerous studies have significantly contributed to understanding landfill sites and environmental challenges in specific regions, particularly the Middle East. For instance, case studies in Iraq: Pshdar area in Sulaymaniyah province [18], Al-

Hillah District of Babylon [34], Babylon Governorate [9], for the landfill in Al-Musayiab District of Babylon [35], Al-Hashimiyah District of Babylon [36], contribute insights from a case study in Al-Kufa [37], a case study in the Tanjero River basin [38], Nasiriyah [39], Al-Diwaniyah City [40], and the Al-Najaf Governorate [41]. Studies from Iran include Behbahan [42], Iranshahr [43], Ahvaz [44], Qom [45], Shiraz [46], Shabestar [47], Hamedan province [48], Javanrood County [49], Mahshahr County [50], Karaj [6], Rudbar County [51], and SaharKhiz Region located in Gilan Province [52]. Those from Turkey are Konya [53], Lake Beyşehir catchment area [4], Senirkent–Uluborlu [54], a metropolitan area in the GAP region [55], Istanbul [56], Northern Cyprus [57], and Aksaray province [58]. From Saudi Arabia include Asir Region [59], Makkah [60], and Dammam [61].

Landfill sites pose significant environmental challenges around the world. Therefore, a concerted global research effort is underway to develop sustainable waste management solutions. For example, in India, Ali et al. [62] conducted a case study of Memari Municipality, Santhosh & Sivakumar Babu [63] had a case study for Bengaluru city, and Deswal & Laura [64] in Rohtak city. Sureshkumar et al. [65] conducted a study for Kanchipuram, while Hazarika & Saikia [66] focused on the Guwahati Metropolitan district. Majid & Mir [67] conducted a case study of Srinagar city. Moreover, Wang et al. [1] conducted a case study in Beijing, China, and Ding et al. [68] conducted a case study in Shenzhen, China.

This study endeavors to identify the optimal landfill site within the Ranya District through the integration of GIS and AHP. The process involves meticulous data collection and incorporation into the GIS platform, followed by a comprehensive evaluation based on the criteria of a sanitary landfill. Adopting this approach also aims to mitigate the potential dispersion of materials and liquids into the surrounding waterways and ground, thereby safeguarding the environment and minimizing adverse effects on the health of the local community. Through the utilization of GIS and AHP, the study considers contributing to the establishment of a landfill site that not only meets the technical requisites but also aligns with environmental sustainability and public health considerations in the Ranya District.

2. Study Area

The present study designates the Ranya District as its focus area. Ranya belongs to the Sulaymaniyah province in Iraq and is located in the northwest, approximately 104 km from Sulaymaniyah city. Ranya comprises five sub-districts (Ranya, Chwarqurna, Hajiawa, Betwata, and Sarkapkan). Moreover, the district's population in 2019 was 258,782 [69]. The Ranya District area is about 882 km^2 and geographically situated between latitude (36° 38′ 46′′ and 36° 04′ 47′′) and longitude (45° 38′ 31′′ and 45° 99′ 03′′), as shown in Fig. 1. Its geology is alluvial sediments that include gravel, sand, silt, and clay. Additionally, the district's climate is characterized by a Mediterranean climate, which is dry and hot in the summer, while its winter is wet and cold [70].

Selecting landfill sites in the Ranya District is crucial due to its significant waste disposal challenges, including inefficient waste management techniques. Population density, geography, and existing infrastructure emphasize the need for intelligent decision-making to promote sustainability in waste management efforts. However, the district has no appropriate way to dispose of waste. Currently, the only method used to dispose of municipal solid waste in the region is the open dumping method, as shown in Fig. 2. The existing dumping areas are not appropriate and are not scientifically suitable according to the standards of landfill site selection. The current locations designated for dumping are unsuitable and do not meet the scientific criteria outlined for proper landfill site selection. It is widely recognized that these dumping sites have numerous harmful effects on the surrounding environment. The research conducted by Hamza and Ahmed [71] investigated solid waste production within the district of the study area. Their findings revealed that the total amount of solid waste generated in the district was estimated at 286.9 tons per day, which equated to 1.108 kilograms per capita per day. They noted that the main component of its solid waste was organic materials, which formed about 67% of the total solid waste.

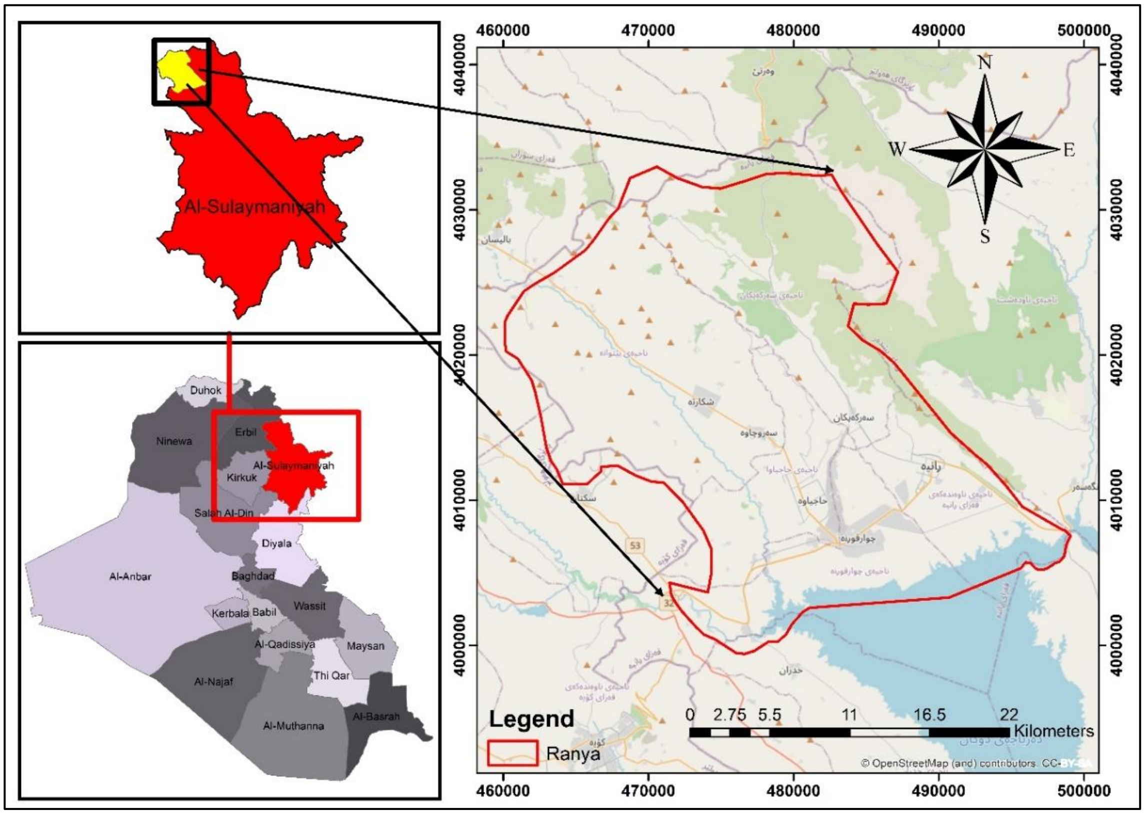


Fig. 1. Ranya District on the Iraqi map.


a.
b.

Fig. 2. (a) Ranya open dumpsite, and (b) Hajiyawa open dumpsite.

3. Data Collection

The most challenging step in this research study was data collection, primarily due to the need for a reliable data source in the study area. Nevertheless, seventeen data layers were created to address this gap by aggregating information from various spatial data sources for the current study. The collected data encompassed rivers, elevation, lakes, geology, agricultural lands, slope, roads, groundwater depth, power lines, archaeological sites, infrastructure, villages, pipelines, urban centers, aspects (wind map), quarrying, and forests. These factors were categorized into one main group, as depicted in Fig. 3. Their significance lies in their pivotal role in site selection for solid waste disposal in the region. The data, meticulously obtained from diverse sources, was processed and stored in the form of digital maps, specifically in the shapefile format, along with raster layers.

The Digital Elevation Model (DEM) data with a grid resolution of 12.5×12.5 meters was acquired from NASA's Earth data website (https://search.earthdata.nasa.gov). The ArcGIS software was used to process the NASA data, generating elevation, slope, aspect, and river streams. The geological data, digitized from Iraq's 1:1,000,000 scale geological map was sourced from the Geological Survey website at (http://en.geosurviraq.iq/). The shapefiles of agriculture, quarrying, forest, settlements, surface waters, and roads were achieved from the region's satellite image resolution of 50 cm. The Directorate of Archeology in Ranya City provided data on archeological sites. A comprehensive groundwater investigation was conducted in the study area, gathering data on about 80 water wells and their depths. Pipeline data were obtained from the Raparin water directorate, and the Directorate of Raparin administration provided information on agricultural land. Subsequently, ArcGIS software was used to convert it into a shapefile. Finally, the groundwater raster layer was generated using the kriging interpolation tool. A multi-layered methodology was employed, in which criteria were systematically organized into sub-criteria, relying on field-validated data in concordance with established literature. The resultant ratings for each sub-criterion are illustrated in Table 1.

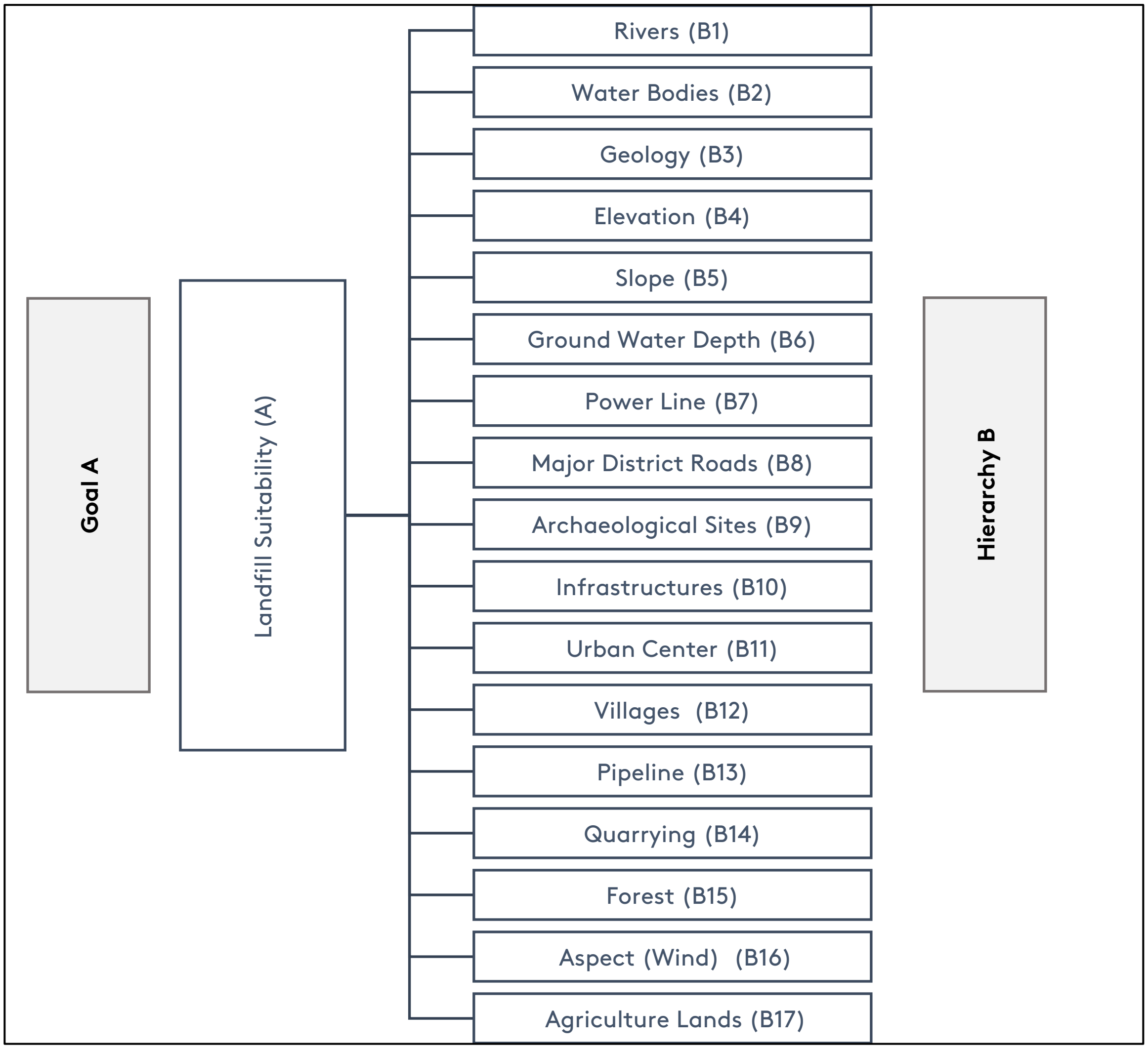


Fig. 3. Hierarchy of data structure.

Table 1. Criteria summary used in the analysis.

No.	Criteria	Sub-criteria value	Sub-criteria scoring	Normalized Weights
1	Rivers (m)	0-500 500-1000 1000-2000 >2000	0 5 8 10	0.110858
2	Water bodies (Lakes) (m)	0-500 500-1000 1000-2000 >2000	0 5 8 10	0.110858
3	Geological properties of the land	Dolomite, Limestone, and Massive Limestone Rock Fragments and Soil Deposits Dokan Lake Limestone, Dolomite, and Cherty Shale	5 7 0 10	0.056553
4	Elevation (MSL)	488-530 530-580 580-630 630-680 >680	10 7 5 3 0	0.060559
5	Slope (degree °)	0-10 10-20 20-30 > 30	10 5 3 0	0.069084
6	Ground Water depth (m)	0-12 12-50 50-100 >100	0 4 8 10	0.153303
7	Power Lines (m)	0-50 50-150 >150	0 3 10	0.018596
8	Major district Roads (m)	0-500 500-1000 1000-2000 >2000	0 6 10 7	0.043698
9	Archaeological Sites (m)	0-1000 >1000	0 10	0.030705
10	Infrastructures (m)	0-500 >500	0 10	0.027529
11	Urban centers (m)	0-3000 3000-12000 12000-16000 >16000	0 10 7 4	0.110693
12	Villages (m)	0-800 >800	0 10	0.05316
13	Pipeline	0-100 >100	0 10	0.016639
14	Quarrying (m)	0-100 >100	0 10	0.015676
15	Forest (m)	0-100 100-300 >300	0 7 10	0.027809

No.	Criteria	Sub-criteria value	Sub-criteria scoring	Normalized Weights
16	Aspects (Wind Direction)	Flat NE, and S N, and E SE, SW, NW, and W	5 3 10 7	0.064819
17	Agricultural	Class I Class II	0 10	0.029463

4. AHP's Criteria Weights Evaluation

The AHP technique was employed to assess each criterion, facilitating the prioritization of multiple essential objectives. This influential method is adept at solving complex problems with numerous interconnected objectives. Specific criteria were weighted based on their importance and suitability in establishing the landfill siting hierarchy and decision model. The study considered seventeen criteria variables, all listed under one main group of factors. These factors were further delineated by sub-criteria, as depicted in Fig. 4. Subsequently, sub-criteria weights were assigned to each criterion through a comprehensive review of existing literature and discussions with field experts.

Pairwise comparisons were employed, with the decision makers' goals in mind, to determine the relative importance of various attributes. Buffer zones around prohibited regions were established by assigning a zero value to sub-criteria. The pairwise comparisons were based on matrix values, where 1, 3, 5, 7, and 9 denoted equal importance, weak importance, vital importance, considerable importance, and absolute importance, respectively, while median values between adjacent judgments were 2, 4, 6, 8, and 10. Furthermore, when comparing activity i to activity j and assigning one of the nonzero numbers listed above to activity i, activity j received the reciprocal value in the comparison, as developed by Saaty [22]. Each criterion calculated its weight (W), and each factor was standardized to determine the criterion weight (wi).

The consistency of the weightings assigned to criteria in the pair-wise comparison matrix was thoroughly examined by dividing the consistency index (CI) by the random index (RI), resulting in the determination of the consistency ratio (CR) as outlined by Arjmandzadeh et al. [72]. This investigation involved the utilization of the random index (RI) value of 1.6086 and the consistency index (CI) value of 0.079 across seventeen criteria, as established by Alonso & Lamata [73]. The average compatibility index is estimated by using the proposed matrix by Saaty [74], and CI is the compatibility index calculated using CI = $(\lambda_{max}-n)/(n-1)$, while the λ_{max} is the largest eigenvalue of the matrix and n is the matrix order. The calculated consistency ratio (CR) is 0.05, which falls below the threshold of 0.1, indicating an acceptable level of consistency.

The weights for seventeen criteria were determined through a pairwise comparisons matrix. The LSI was then computed by multiplying the weight assigned to each criterion with the weight of each sub-criterion. The final output map was generated by applying these calculations. The "Weight Overlay" spatial analysis tool in ArcGIS software was employed to achieve this, and the outcomes are presented in Table 2. The calculation process for the LSI proceeded as follows:

LSI= (B1wi × B1swii) + (B2wi × B2swi) + (B3wi × B3swi) + (B4wi × B4swi) + (B5wi × B5swi) + (B6wi × B6swi) + (B7wi × B7swi) + (B8wi × B8swi) + (B9wi × B9swi) + (B10wi × B10swi) + (B11wi × B11swi) + (B12wi × B12swi) + (B13wi × B13swi) + (B14wi × B14swi) + (B15wi × B15swi) + (B16wi × B16swi) + (B17wi × B17swi)

The terms “B1wi, B2wi, B3wi, B4wi, B5wi, B6wi, B7wi, B8wi, B9wi, B10wi, B11wi, B12wi, B13wi, B14wi, B15wi, B16wi, and B17wi” represent the criteria weightings. The terms “B1swi, B2swi, B3swi, B4swi, B5swi, B6swi, B7swi, B8swi, B9swi, B10swi, B11swi, B12swi, B13swi, B14swi, B15swi, B16swi, and B17swi” are indications specifying the weightings of sub-criteria for each criterion.

Criteria weights guide landfill site selection by reflecting the importance of each factor. Through rigorous pairwise comparisons and expert consultations, stakeholder preferences are captured, enabling comprehensive decision-making [75, 76]. Weights prioritize factors like proximity to sensitive areas and environmental impact, ensuring regulatory compliance and community well-being [77]. Consistency analysis helps ensure that the weights are internally consistent and reliable [78]. These weights serve as a roadmap, fostering transparent decision-making and minimizing environmental harm. They translate complex methodology into actionable insights, facilitating informed decisions [79]. For instance, in this study, weights may assign higher importance to factors like groundwater depth, slope, and distance from urban centers, reflecting the greater risk of groundwater contamination. Conversely, Kang et al. [80] emphasized the importance of considering proximity to roads when selecting landfill sites. Opting for locations distant from populated areas and major roads can help mitigate air and noise pollution, safeguarding communities and environmental well-being.

5. Results and Discussion

Inadequate selection of dumpsite placement harms the economy, environment, and ecology, as well as poses health issues. Solid waste disposal in landfills remains a common practice, even in developing nations. Despite substantial daily waste production, there remains a deficiency in daily collection, segregation processes, efficient transportation, and the availability of suitable waste disposal sites [81]. A recent investigation revealed that from 2005 to 2023, over a hundred studies on landfill site suitability were conducted using GIS and various multi-criteria decision-making techniques [82]. Consequently, the importance of researching the selection of waste dumping sites in expanding urban areas is underscored in this study. This study employed the AHP in conjunction with GIS software to evaluate the appropriateness of landfill site selection within the specified research area. GIS was instrumental in applying spatial statistics, grouping locations with the highest suitability, and managing extensive spatial data derived from diverse sources. The final map was produced using the specified calculations, utilizing the spatial analysis tool in ArcGIS software. The results are displayed in Table 2.

Table 2. Normalized weights calculation table.

Criteria	Rivers	Water Bodies (Lakes)	Geology	Elevation	Slope	Groundwater Depth	Power Line	Major District Road	Archaeological Sites	Infrastructures	Urban Center	Villages	Pipeline	Quarrying	Forest	Aspect (Wind)	Agricultural	Normalized Weights
Rivers	1	1	2	4	3	0.5	7	3	4	6	0.5	3	4	5	4	2	3	0.110858
Water Bodies (Lakes)	1	1	2	4	3	0.5	7	3	4	6	0.5	3	4	5	4	2	3	0.110858
Geology	0.5	0.5	1	2	1	0.25	5	1	5	4	0.25	0.5	3	3	1	0.5	2	0.056553
Elevation	0.25	0.25	0.5	1	1	0.25	6	0.5	2	5	0.5	2	5	4	2	1	3	0.060559

Criteria	Rivers	Water Bodies (Lakes)	Geology	Elevation	Slope	Groundwater Depth	Power Line	Major District Road	Archaeological Sites	Infrastructures	Urban Center	Villages	Pipeline	Quarrying	Forest	Aspect (Wind)	Agricultural	Normalized Weights
Slope	0.33	0.33	1	1	1	0.25	5	3	2	3	0.5	0.5	6	6	3	2	3	0.069084
Groundwater Depth	2	2	4	4	4	1	7	4	5	6	2	3	7	7	3	2	3	0.153303
Power Line	0.14	0.14	0.2	0.16	0.2	0.14	1	0.75	0.5	0.5	0.25	0.5	1	1	0.75	0.5	0.75	0.018596
Major District Road	0.33	0.33	1	2	0.33	0.25	1.33	1	2	1	0.5	0.75	4	4	2	0.5	0.75	0.043698
Archaeological Sites	0.25	0.25	0.2	0.5	0.5	0.2	2	0.5	1	1	0.25	0.5	2	3	2	0.75	1	0.030705
Infrastructures	0.16	0.16	0.25	0.2	0.33	0.16	2	1	1	1	0.25	0.75	3	2	1	0.5	1	0.027529
Urban Center	2	2	4	2	2	0.5	4	2	4	4	1	2	5	6	4	1	3	0.110693
Villages	0.33	0.33	2	0.5	2	0.33	2	1.33	2	1.33	0.5	1	3	4	2	0.75	2	0.05316
Pipeline	0.25	0.25	0.33	0.2	0.16	0.14	1	0.25	0.5	0.33	0.2	0.33	1	1	0.75	0.25	0.5	0.016639
Quarrying	0.2	0.2	0.33	0.25	0.16	0.14	1	0.25	0.33	0.5	0.16	0.25	1	1	0.5	0.25	0.75	0.015676
Forest	0.25	0.25	1	0.5	0.33	0.33	1.33	0.5	0.5	1	0.25	0.5	1.33	2	1	0.5	1	0.027809
Aspect (Wind)	0.5	0.5	2	1	0.5	0.5	2	2	1.33	2	1	1.33	4	4	2	1	4	0.064819
Agricultural	0.33	0.33	0.5	0.33	0.33	0.33	1.33	1.33	1	1	0.33	0.5	2	1.33	1	0.25	1	0.029463

The research systematically considered all criteria relevant to landfill site selection, assigning weights to each criterion for every layer using the ArcGIS weight overlay tool, as determined by the final AHP suitability map; the research included seventeen criteria variables grouped under a primary set of factors. These factors were subdivided into sub-criteria, which are illustrated in Figure 4.

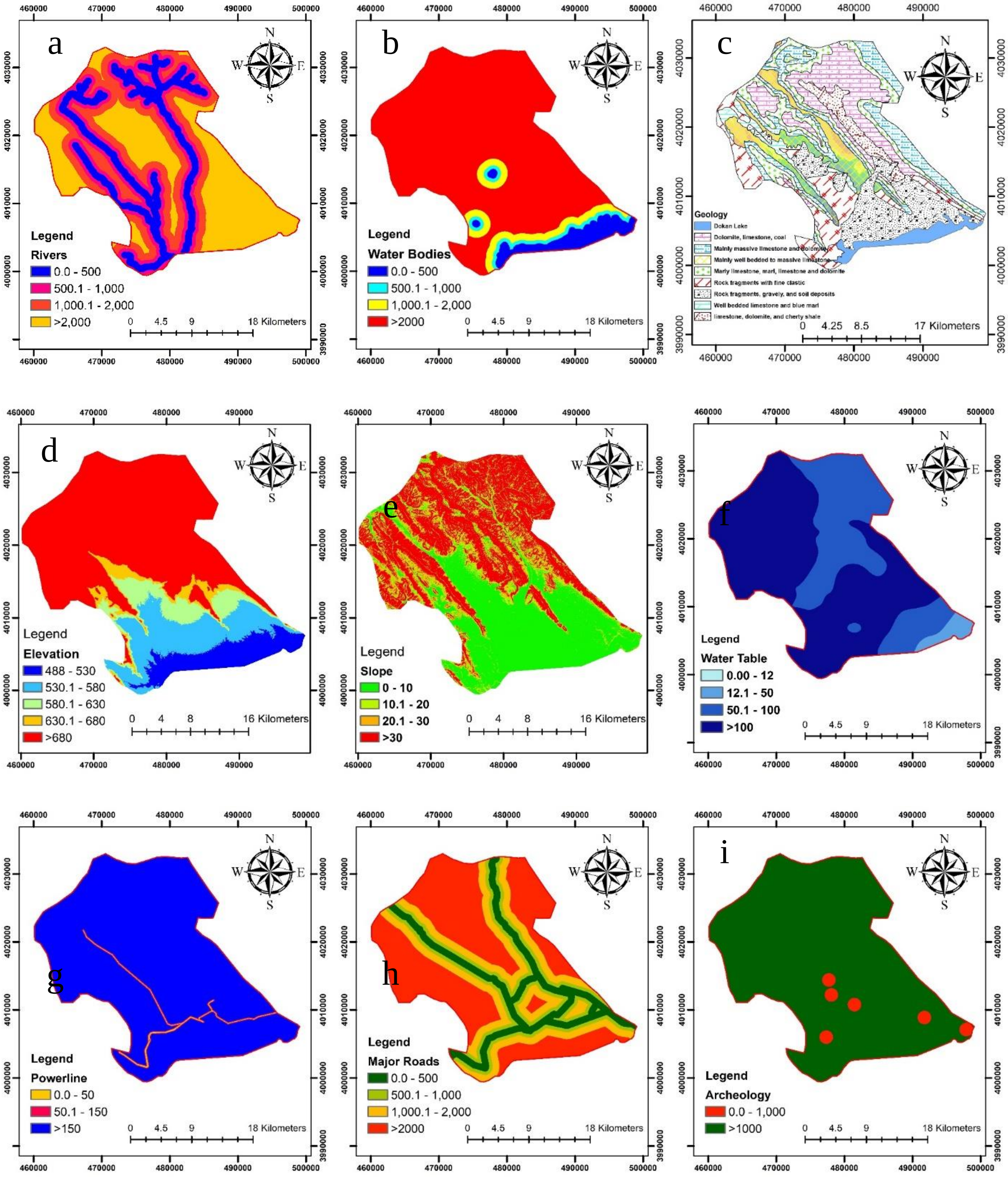


Fig. 4. Maps show the suitability of standardized criteria for landfill sites from top to bottom, indicating the sub-criteria assigned to the layer of **a.** Rivers, **b.** Water Bodies, **c.** Geology, **d.** Elevation**, e.** Slope, **f.** Groundwater Table, **g.** Power Lines, **h.** Major Roads, **i.** Archeology, **j.** Infrastructures, **k.** Urban Center, **l.** Villages, **m.** Pipeline, **n.** Quarrying, **o.** Forest, **p.** Aspect (Wind), and **q.** Agricultural.

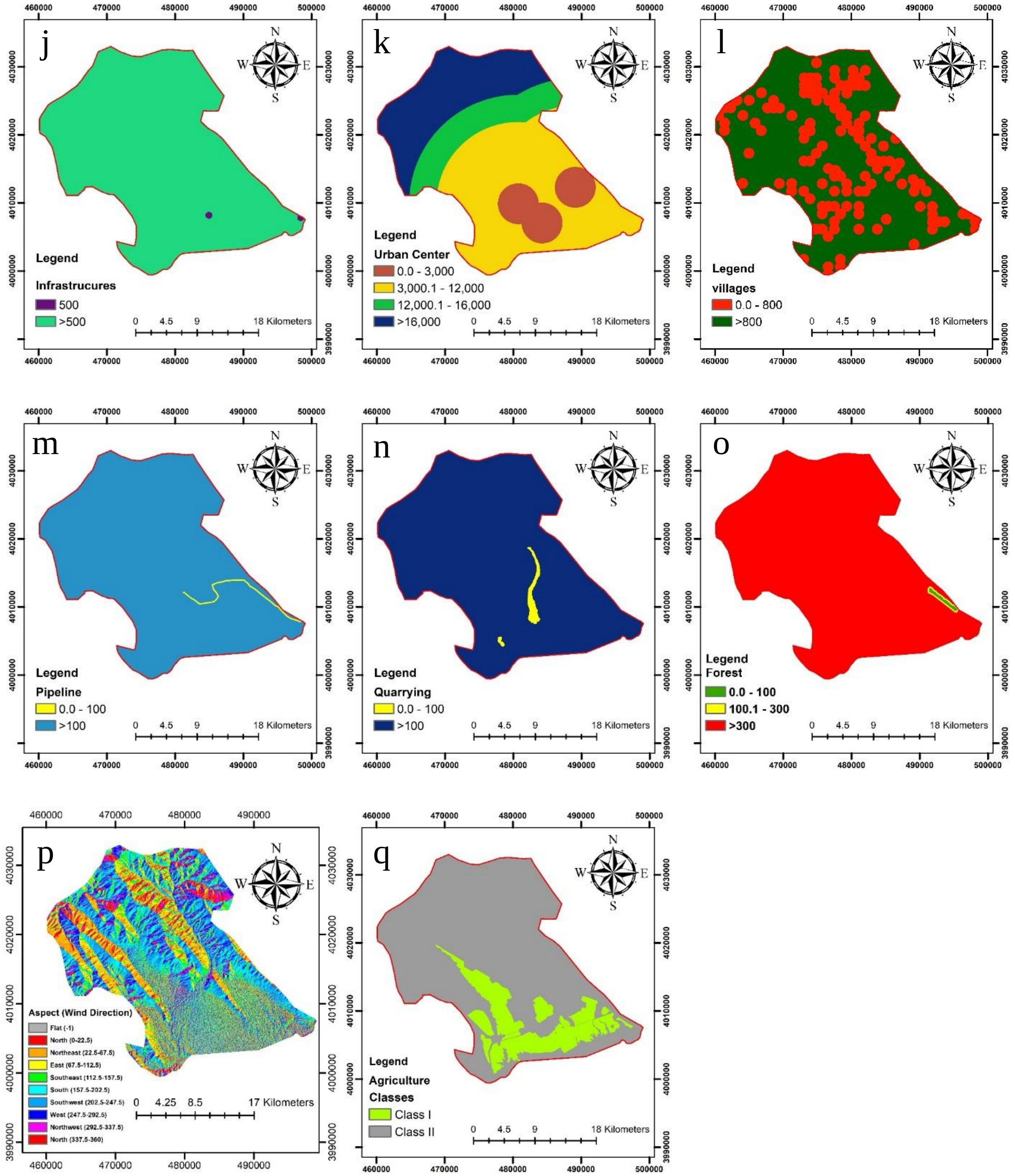
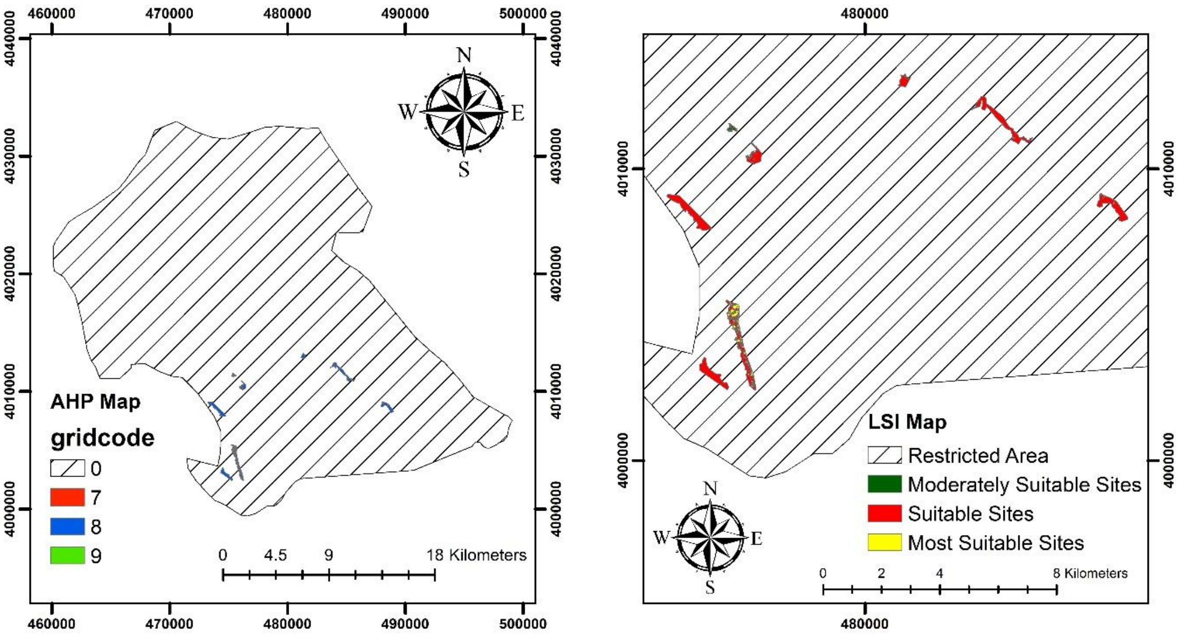


Fig. 4. Continued.

In the study area, a conclusive production map of the LSI was generated, reflecting the suitability of locations for landfill placement. The LSI map was categorized into four classes: 1. Unsuitable sites, 2. Moderately suitable sites, 3. Suitable sites, and 4. Most suitable sites. This meticulous site selection process proved invaluable for future planning, enabling the acceptance of site suitability with the maximum operational period for the chosen candidate site. The presented case study illustrated the systematic identification of optimal sites and evaluation of all candidate sites based on predefined factors overlaid with their respective weights.

Finally, the most suitable landfill sites were identified and could be regarded as the primary candidates for optimal landfill placement. This research presented scientific evidence on the research topic. The results could function as reference points for identifying disposal sites in areas sharing similar attributes, offering decision-makers a thorough analysis and support in tackling issues related to waste management. This could aid in the process of choosing the most appropriate landfill sites in the Ranya District. Seventeen criteria were utilized: rivers, water bodies (lakes), elevation, groundwater depth, geology, slope, power lines, major district roads, archaeological sites, villages, infrastructures, urban centers, pipelines, quarrying, forests, aspect (wind), and agriculture. These factors were further divided into sub-criteria, considering both environmental and economic aspects. In GIS, each criterion was digitized. Subsequently, a value was assigned for each sub-criterion along with a corresponding weight using the AHP method, as illustrated in Table 1. Finally, an AHP map was generated with four distinct grid codes, which were then converted into the LSI, as depicted in Fig. 5. The codes included 0 (referring to restricted areas), 7 (moderately suitable sites), 8 (suitable sites), and 9 (indicating the most suitable sites).



(a) (b)

Fig. 5. (a) AHP map and (b) LSI map.

Additionally, the area of each selected site was computed. The areas for moderately suitable sites were 68320.14377 m², suitable sites were 2051852.218 m², and the most suitable sites were 275889.0406 m². The ratio of each selected area to the whole study area (moderately suitable area, suitable area, and the most suitable area) was (0.01, 0.29, and 0.04), respectively. In GIS, the suitable areas were located in eight places, as shown in Table 3. When comparing these findings to those of the neighboring district of Pshdar, as investigated by Manguri & Hamza [18], striking similarities emerge in terms of both criteria and other physical and geographical characteristics. Both districts share similarities in their developmental criteria and physical features, such as climate and terrain, which contribute to the comparability of their results.

Table 3. Nominated sites and their areas.

Sites	Area m^2	Easting (m)	Northing (m)
Site 1	293008	488590	4008730
Site 2	390108	484033	4012400
Site 3	97863	481331	4013040
Site 4	184940	476212	4010360
Site 5	49244	475432	4011370
Site 6	399080	473912	4008620
Site 7	701251	475508	4004990
Site 8	281340	474492	4003230

The findings indicated that all the sites were located in close proximity to mountainous areas and concentrated in the southern region of the study area. This is because the northern part is predominantly occupied by mountains and residential areas, making it less suitable for landfill sites. While a large flat area in the southern part of the study area was suitable for most criteria, these areas are currently utilized for agricultural purposes and, therefore, cannot be employed as landfill sites.

The identification of optimal landfill sites could allow policymakers and waste management authorities to make more informed decisions regarding waste disposal infrastructure. By selecting sites that minimize environmental degradation and public health risks while maximizing efficiency, these findings could pave the way for more sustainable waste management practices in the district. Implementation of these findings could lead to improved waste disposal processes, reduced transportation costs, and enhanced overall environmental stewardship. Additionally, the integration of modern technologies and best practices in waste management could further augment the effectiveness of these policies. Finally, local authorities could choose the most preferred locations based on annual waste disposal rates, with the remaining ones serving as backup options for landfill sites.

6. Conclusions

Decision-makers, engineers, and planners possess the capability to leverage methodologies centered around GIS for conducting land suitability studies, thereby establishing a systematic framework for land development. This specific study utilized GIS in conjunction with the AHP to identify optimal locations for landfill sites. The seventeen criteria were mapped and assigned sub-criteria within GIS software. Then, the normalized weight of each criterion in AHP was identified to generate the final LSI map for the region. As a result of this process, only 0.34% of the designated study area was suitable for establishing a landfill, amounting to a total of 2,396,062 m^2. The suitable sites were categorized into moderately suitable, suitable, and most suitable sites categories to ensure that environmental sustainability was balanced with solid waste management needs. Thus, the indicated classification gave the most suitable approach for future projects.

These indexed sites were located at eight different locations distributed across the district, named Site 1, Site 2, Site 3, Site 4, Site 5, Site 6, Site 7, and Site 8. The areas of these sites are 293,008 m^2, 390,108 m^2, 97,863 m^2, 184,940 m^2, 49,244 m^2, 399,080 m^2, 701,251 m^2, and 281,340 m^2, respectively. These results indicated the importance of incorporating evidence-based decision-making in waste management policy by considering economic, social, and environmental factors to promote sustainability.

Recommendations

The following are recommendations based on the landfill site selection in the Ranya District using GIS and AHP:

- Encourage the initiation of longitudinal studies to monitor the environmental impacts and effectiveness of the newly selected landfill sites over time.
- Suggest integrating remote sensing and machine learning to improve the accuracy and predictive power of landfill site selection using GIS.
- Urge local governments to establish regulations and select landfill sites based on the study's findings and annual waste disposal rates to ensure sustainable operations, reserving additional sites as backups.

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