Journal of Natural Science Review

Vol. 3, No. 2, 2025
https://kujnsr.com
e-ISSN: 3006-7804

Optimizing Waste Transfer Station Siting in Kabul Using GIS-Based Multi-Criteria Decision Analysis

Mohammad Kamil Halimee✉[1], Mohammad Seddiq Sadeq[2], Ali Kaihan Stanikzai[3], Sayed Murtaza[4]

[1,2,3,4] Kabul University, Urban Design and Planning Department, Faculty of Engineering, Kabul, AF
✉E-mail: kamil.wardak@gmail.com

ABSTRACT

Efficient siting of waste transfer stations is vital for reducing operational costs, improving recycling outcomes, and minimizing environmental impacts in rapidly urbanizing cities like Kabul. Despite the Kabul Urban Design Framework (KUDF, 2018) identifying nine proposed locations for transfer stations, not a single facility has been implemented, largely due to financial limitations and uncertainty over the technical suitability of those sites which resulted in delays in implementation of transfer stations and inefficient sorting and hauling of waste to the Gazak 2 landfill limiting recycling efforts and landfill diversion due to mixed and contaminated waste. This study applies a GIS-based Multi-Criteria Decision Analysis (MCDA) framework, incorporating the Analytic Hierarchy Process (AHP) and Weighted Linear Combination (WLC), to identify spatially optimal locations for waste transfer stations in Kabul. Four criteria—proximity to main roads, residential areas, water bodies, and terrain slope—were evaluated and weighted using expert input. Results show that only 18.16% of Kabul's land is highly suitable for transfer station siting, with buildings and roads being the most influential factors. When overlaid with the KUDF-proposed sites, six of nine were found to be located within suitable or highly suitable zones. The remaining sites require further reassessment due to proximity to sensitive areas or infrastructural constraints. The findings highlight the critical role of spatial decision support in addressing implementation delays and improving solid waste logistics. This study provides a replicable framework and practical guidance for Kabul Municipality and other cities facing similar challenges in optimizing waste management infrastructure.

ARTICLE INFO

Article history:

Received: March 2, 2025
Revised: June 07, 2025
Accepted: June 25, 2025

Keywords:

Analytic Hierarchy Process (AHP); Kabul Urban Design Framework; Siting; Urban Waste Management; Waste Transfer Stations

To cite this article: Halimee, M. K., Sadeq, M. S., Stanikzai, A. K., & Hassaini, S. M. (2025). Optimizing Waste Transfer Station Siting in Kabul Using GIS-Based Multi-Criteria Decision Analysis. *Journal of Natural Science Review*, *3*(2), 123–141. https://doi.org/10.62810/jnsr.v3i2.206

Link to this article: https://kujnsr.com/JNSR/article/view/206

INTRODUCTION

Urban solid waste management is a growing challenge in rapidly expanding cities, especially in fragile and post-conflict contexts where infrastructure development lags behind population growth (Kaza et al., 2018). Inadequate planning and absence of intermediate waste handling infrastructure—such as transfer stations—can lead to inefficient logistics, environmental degradation, and missed opportunities for resource recovery. Waste transfer stations serve a critical role in modern waste systems by consolidating waste near its source, reducing long-haul transportation distances, lowering fuel consumption, and creating opportunities for pre-sorting and recycling (Bovea & Powell, 2006; Komilis, 2008).

Kabul, the capital of Afghanistan, illustrates these issues with exceptional urgency. With a population exceeding five million (NSIA, 2024) and rapid, often unregulated urban expansion (Khoshbeen et al., 2020), the city generates more than 3,000 tons of municipal solid waste every day, out of which 38% is recycled, 44% is hauled to landfill and 18% is burned, buried or disposed informally (Nikzad, 2020). Currently, most of the waste is hauled directly to the Gazak 2 landfill located roughly 30 kilometers outside the urban core—without the use of any operational standard transfer stations (Ullah et al., 2022) while some waste is informally sorted in the existing transfer station. Although the Kabul Urban Design Framework (KUDF), adopted in 2018 (MUDL & Sassaki, 2018), proposed nine sites for transfer station development, none have been implemented to date. This gap is due not only to budgetary constraints but also to hesitancy from the municipality regarding the suitability of the proposed locations.

The consequences of this inaction extend beyond inefficient transportation. Recent assessments at Gazak 2 by NEPA auditors (2019) show that over 32% of waste arriving at the landfill consists of organic material, much of which could have been recovered if sorted earlier in the waste stream(Nikzad, 2020). Informal recyclers, who play a vital role in Kabul's waste reduction system, are unable to recover food waste, plastic bags, or cardboard once these materials are mixed and contaminated. Transfer stations, if properly sited and managed, could provide critical infrastructure for intermediate sorting and recovery—boosting recycling rates, supporting livelihoods, and reducing the burden on landfills. based on existing studies and projections, estimates suggest that better transfer station coverage could reduce landfill waste by at least 11%, while also increasing employment opportunities for informal recyclers (Nikzad, 2020).

International evidence is supporting the benefits of transfer stations (Rafiee et al., 2011; Zamorano et al., 2009). Despite policy frameworks that exist within Afghanistan, implementation remains stalled due to technical uncertainty and lack of spatial analysis. Addressing these gaps through context-sensitive planning is therefore essential. This study applies a GIS-based Multi-Criteria Decision Analysis (MCDA) framework, integrating the Analytic Hierarchy Process (AHP) and Weighted Linear Combination (WLC), to identify the most suitable areas for siting transfer stations in Kabul. It also evaluates how well the KUDF-proposed sites align with objective spatial suitability area and offers decision-makers evidence-based guidance to move forward with implementation.

An important consideration in planning for transfer stations is the composition and volume of municipal solid waste. Kabul's municipal solid waste (MSW) stream is predominantly composed of biodegradable and recyclable materials. Empirical studies estimate that organic waste constitutes approximately 45%, while plastics, paper, and metals collectively account for about 25–30% of the total waste (Forouhar & Hristovski, 2012;

Khoshbeen et al., 2020). The city's average per capita waste generation is estimated to be 0.45 kilograms per day, although the absence of systematic data collection poses challenges to accurate quantification (Nikzad, 2020).

Collection services are provided through a mixed system of municipal and private operators, but the lack of source separation and intermediate sorting leads to contamination, particularly of food waste and plastics—materials that could otherwise be recovered. The situation is worsened by the absence of functional transfer stations, resulting in direct long-haul transport to the Gazak 2 landfill, located approximately 30 kilometers from the city center.

To address inefficiencies in the system, Kabul Urban Design Framework (KUDF) proposed nine strategic sites for transfer stations, as shown in Figure 2; no station was implemented as of 2025.

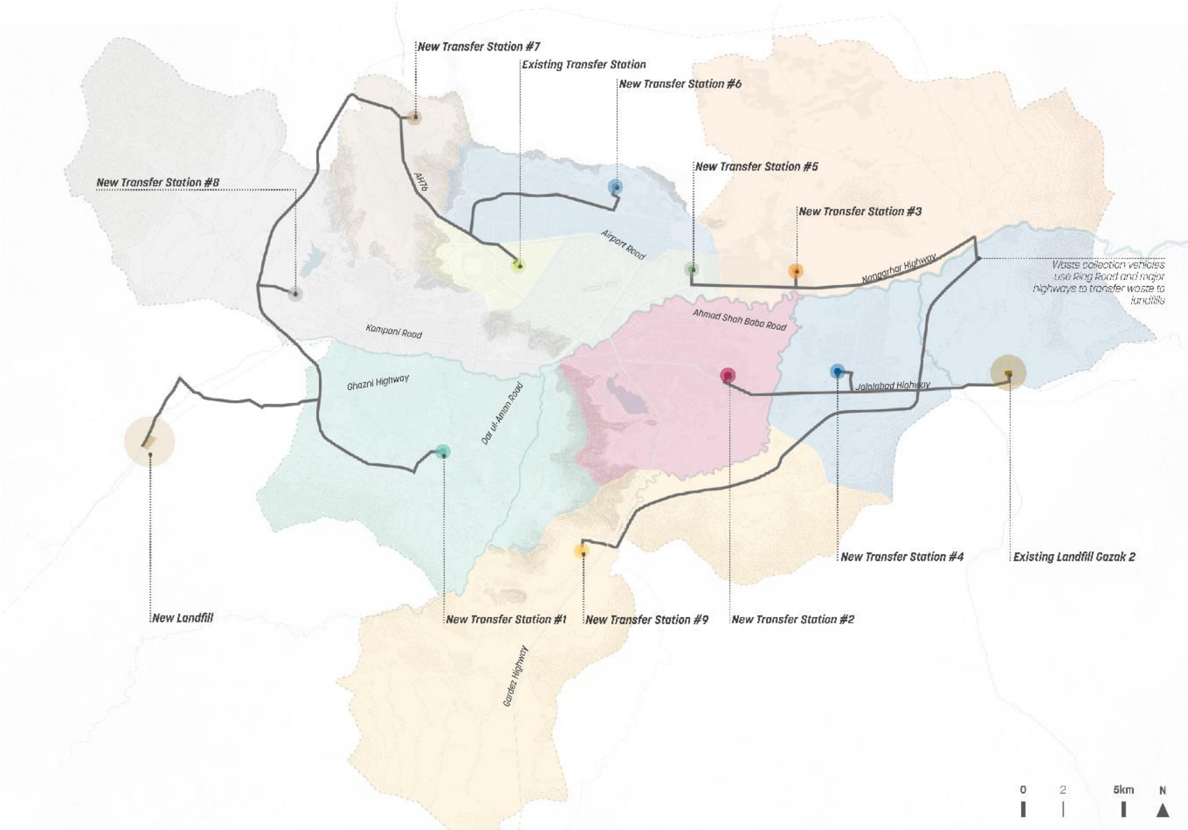

Figure 1. *Proposed Transfer Stations by KUDF, reproduced from (MUDL & Sassaki, 2018)*

The KUDF's proposed locations, visualized in official spatial planning documents, highlight the intention to distribute facilities across key zones to support operational coverage and reduce haul distances (MUDL & Sassaki, 2018). It is envisioned that two landfills will be used to reduce transportation costs: waste from four of the proposed and existing transfer stations would be directed to a newly planned landfill, while waste from five other proposed stations would continue to be hauled to the existing Gazak 2 landfill. It is important to note that the existing transfer station currently functions only as a temporary collection point. Informal recyclers manually extract reusable materials from the delivered waste, but no formal sorting procedures are conducted by the Kabul Municipality.

These limitations in waste characterization, handling, and infrastructure emphasize the need for spatially optimized transfer stations to enable early-stage sorting, support recycling activity, and improve overall system efficiency.

By addressing the technical uncertainty surrounding the siting of waste transfer stations, this research provides practical tools and spatial insights to support improved waste management outcomes in Kabul and other rapidly growing cities facing similar challenges.

METHODS AND MATERIALS

This applied study focuses on supporting evidence-based decision-making for waste transfer station siting, rather than generating new scientific theories. It employs established spatial decision-making techniques, namely the Analytic Hierarchy Process (AHP) and Weighted Linear Combination (WLC)—within a Geographic Information System (GIS) framework. Data sources include scholarly literature, official reports, and relevant records from the Kabul Municipality.

Study Area

The study was conducted in Kabul city, the capital of Afghanistan as illustrated in Figure 1, located at 34°30′N latitude and 69°10′E longitude.

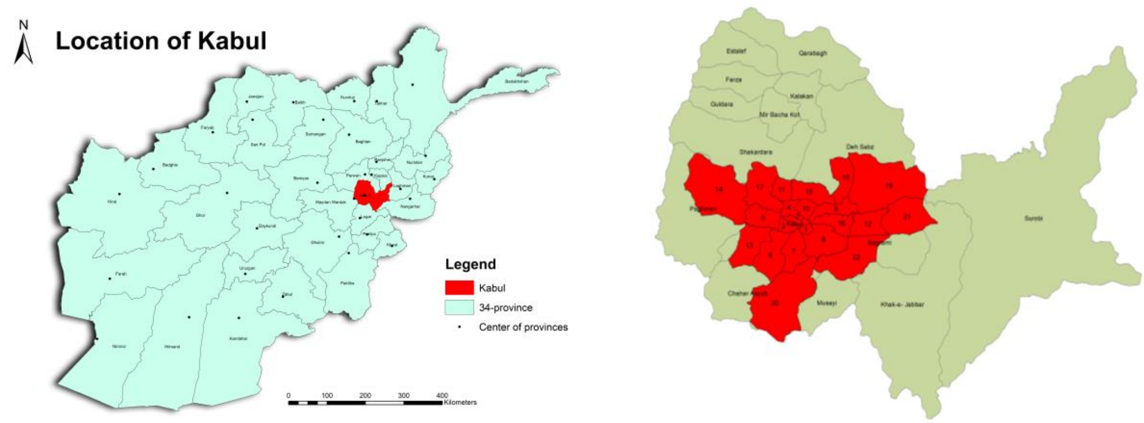

Figure 2. *Location of Kabul Province in Afghanistan (left) and in Kabul City within the Province (Right), Reproduced from (Geofabrik Download Server, n.d.)*

The city hosts over five million residents and comprises 22 administrative districts (NSIA, 2024). Kabul's geography is characterized by a mix of flatlands and surrounding mountainous terrain, with rapid and largely informal urban expansion contributing to significant challenges for urban infrastructure planning (Ahmadi et al., 2024). Despite the Kabul Urban Design Framework (KUDF) adopted in 2018, which recommended the development of strategically located waste transfer stations, no such facilities have yet been established. The current system relies on improper sorting by informal recyclers and direct haulage to the Gazak 2 landfill located nearly 30 kilometers from the city center (Nikzad, 2020; Ullah et al., 2022). This absence of intermediate facilities has contributed to inefficiencies in collection, mixing of organic and recyclable materials, and missed opportunities for informal recycling and early-stage waste separation.

Research Design

This study adopts a spatial Multi-Criteria Decision Analysis (MCDA) approach within a Geographic Information System (GIS) framework to assess the suitability of land for waste transfer stations in Kabul. The objective is not only to optimize logistical operations but also to enhance the overall effectiveness of waste recovery and recycling. The methodology evaluates four key spatial criteria—proximity to main roads, residential areas, water bodies, and terrain slope—that reflect both technical feasibility and environmental and social considerations. For the analysis purposes as shown in FIGURE these criteria were weighted based on AHP pairwise comparison, separate suitability maps of the whole study area were developed for each criteria considering the adopted distance ranges and finally the developed individual suitability maps were overlayed on each other using the weighted linear combination method for which the weightages come the AHP comparison. The findings aim to support evidence-based planning and reduce the hesitation that has delayed implementation of the KUDF transfer station proposals.

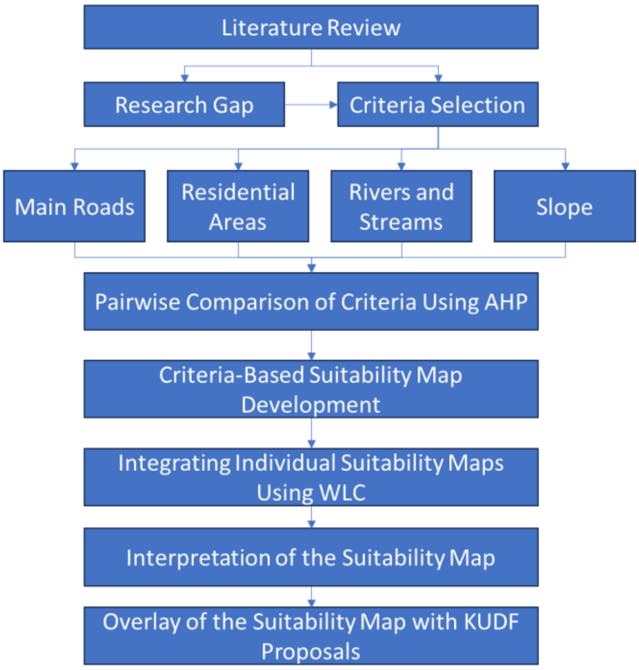

Figure 3. *Research Flow Chart*

Data Sources and Validation

Spatial and attribute data were sourced from multiple authoritative datasets. Road networks, residential footprints, and hydrological features were obtained from the Kabul Urban Design Framework (MUDL & Sassaki, 2018) and OpenStreetMap (Geofabrik Download Server, n.d.). Elevation data were extracted from the 30-meter resolution Digital Elevation Model (DEM) provided by the United States Geological Survey (Chirico & Barrios, 2005). Secondary data related to waste composition and management were gathered from World, and relevant studies such as (Azimi et al., 2020; Forouhar & Hristovski, 2012; Nikzad, 2020; Ullah et al., 2022).

To validate spatial data, cross-referencing was conducted using high-resolution satellite imagery in Google Earth Pro and updated local municipal records. Metadata on resolution, currency, and completeness were examined to confirm the quality and usability of each dataset for urban infrastructure planning. This rigorous validation helped ensure that the suitability analysis reflects current urban conditions and development patterns.

Criteria Selecting and Classification

The classification of spatial criteria into suitability levels reflects both technical feasibility and socio-environmental safeguards necessary for equitable waste infrastructure development. Informed by established guidelines and comparative siting studies, the criteria are generally grouped into three categories: (1) exclusionary, (2) technical, and (3) community-specific factors.

Exclusionary criteria refer to locations legally or environmentally prohibited for development, such as parks, conservation areas, flood zones, and wetlands. These areas are excluded from consideration due to their protected status or high environmental sensitivity.

Technical criteria are focused on operational efficiency and engineering feasibility. These include proximity to main roads for ease of transportation, terrain slope for construction suitability, and distance from water bodies to prevent contamination.

Community-specific criteria aim to minimize social disruption and health risks by avoiding areas near densely populated residential zones.

In this study, the selected criteria were each categorized into three suitability levels—highly suitable, suitable, and less suitable—based on thresholds commonly applied in the literature and adapted to the context of Kabul. The classification ranges are presented in Table 1 below.

This study primarily focuses on technical criteria for site selection, with limited application of exclusionary factors and a constrained social dimension represented mainly by residential density. While Kabul's soils are not uniform, soil type was excluded from the analysis due to data limitations and its relatively lower impact on site suitability in this context.

Table 1: *Suitability Ranges for Site of Transfer Stations*

Criteria	Highly Suitable	Suitable	Less Suitable
Distance from main roads	1000–4000 meters	500–1000 meters	x <500 meters, OR x >4000 meters
Distance from residential areas	>2000 meters	2000–500 meters	x <500 meters
Distance from water bodies/streams	>2500 meters	2500–500 meters	x <500 meters
Slope (gradient)	<6°	6–9°	x <9°

Note: criteria are adopted from (US EPA, 2002), ranges are adopted from (Rafiee et al., 2011; Zamorano et al., 2009)

Exclusionary criteria such as protected areas and floodplains were also only partially considered, reflecting both data availability and local conditions. The selected criteria were classified into three suitability levels—less suitable, suitable, and highly suitable—as summarized in Table 1.

Data Extraction and Criteria Evaluation

Once the criteria were determined, the next step involved extracting spatial datasets corresponding to the selected factors. Two primary types of data were utilized:

a. Slope data, derived from the study's own Digital Elevation Model (DEM) of Kabul at 30-meter resolution, which was used to generate detailed slope maps (see Figure 3).

b. Distance for all other criteria, calculated based on spatial data layers.

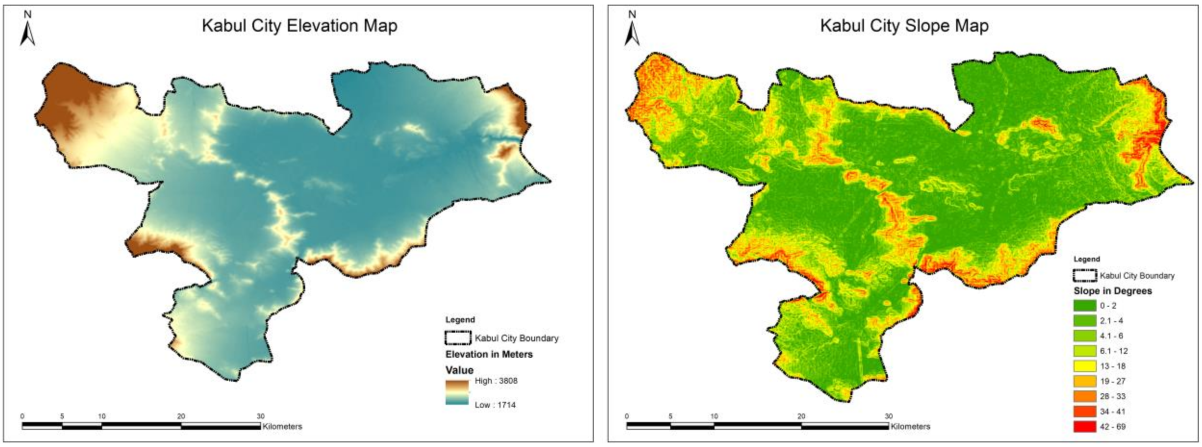

Figure 4. *Elevation and Slope Maps of Kabul City, adapted from (Chirico & Barrios, 2005)*

Slope extraction was particularly important because Kabul is surrounded by mountains, requiring the identification of relatively flat areas for the construction of waste transfer stations, shown in figure 3. Thus, land slope was considered an essential factor in this study. The slope classification for the study area was based on DEM data, with the degree of slope used as the output measurement.

Distances from the roads; waterways and built-up areas as shown in Table 1 were calculated using GIS[1]. In this process, the Euclidean distance, which represents a straight-line distance, was applied to each of the data sets. Specifically, straight-line distances were calculated for the following data sets: main roads, residential areas, and water bodies/streams.

[1] It is worth mentioning that roads data was that of KUDF (MUDL & Sassaki, 2018), the rest of the spatial layers were downloaded from OpenStreet Map (*Geofabrik Download Server*, n.d.).

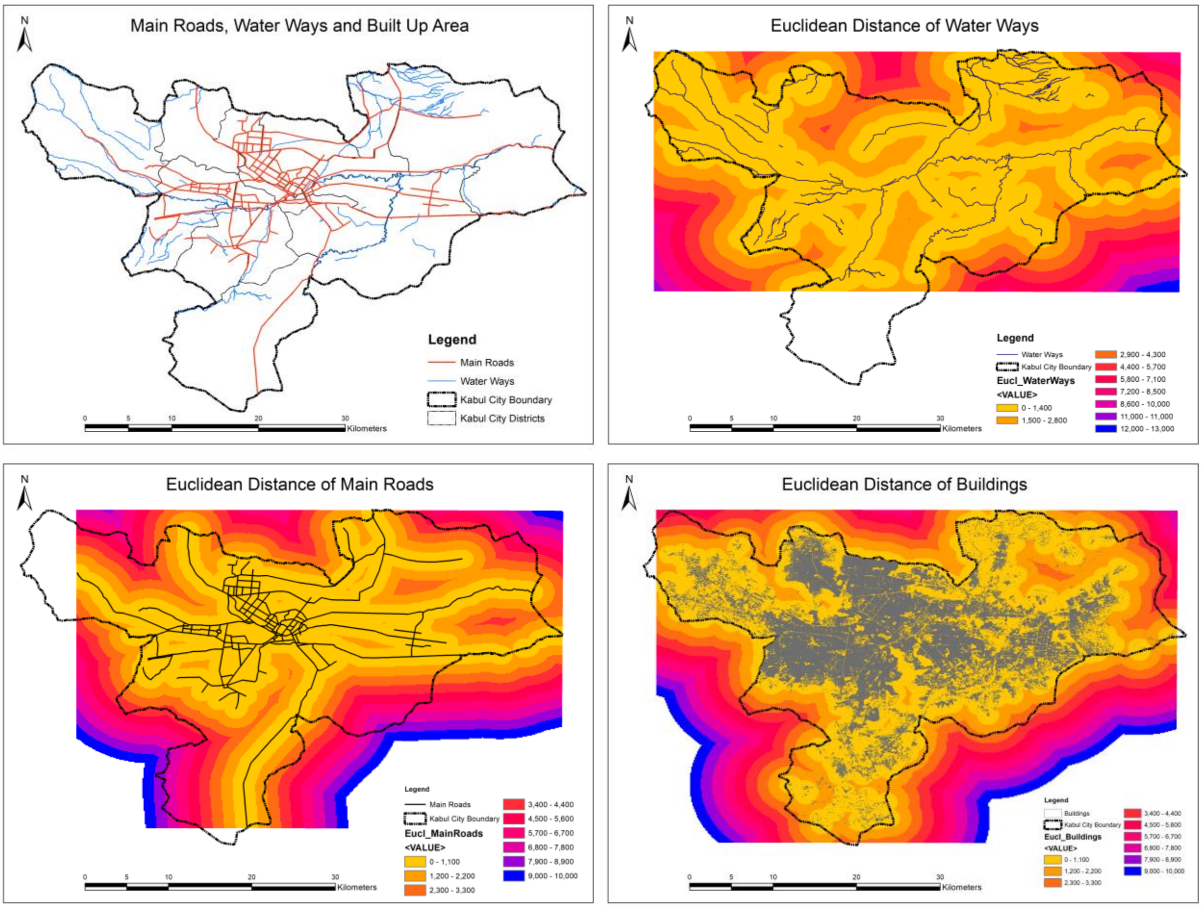

Figure 5. *Networks and Euclidean Distances for Kabul City*

Reclassification of Extracted Data Sets

Reclassification of the extracted data sets, such as the distance from the region's main roads, shown in figure 4 is the first step in building an appropriate model. To combine the various data sets, it is essential to first classify all the specific data sets into a common measurement scale, such as a scale of 1 to 3. This common measurement scale determines how suitable a particular location (or cell) is for siting new waste transfer stations. Higher values indicate more suitable locations, while lower values represent less suitable areas.

For this particular study, all data sets were reclassified into three categories: (1) less suitable areas, (2) moderately suitable areas, and (3) highly suitable areas. The values in the data sets extracted in the previous step are all continuous data that are classified into ranges. Each range of values should be assigned a discrete integer value such as 1, 2, or 3. This discrete classification is crucial because the overlapping weighted inputs, which will be used in the next step of the analysis, must contain discrete integer values. Thus, the extracted data sets, as presented in Table 1, were reclassified into three distinct categories to facilitate the next stages of the analysis.

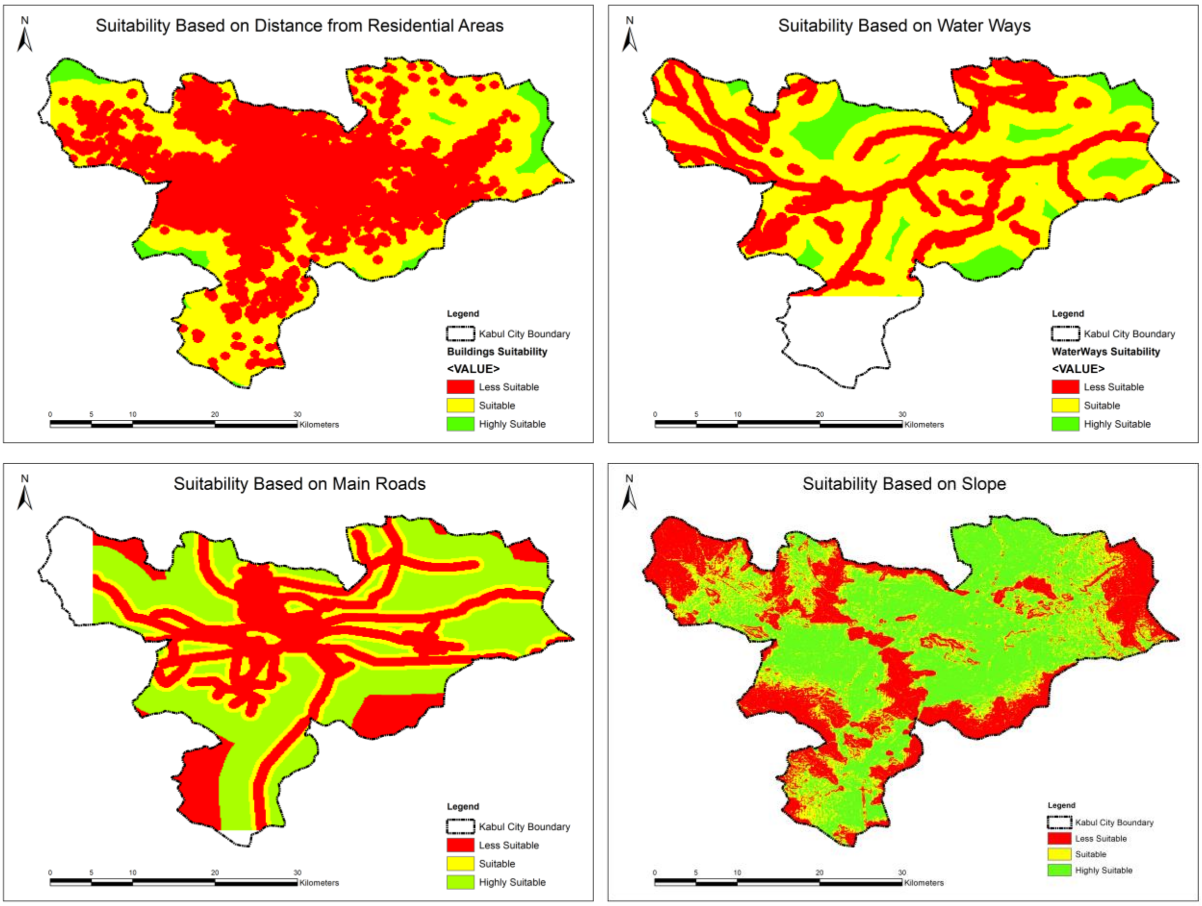

Figure 6*. Suitability Maps based on individual criteria (Residential Areas, Water Ways, Main Roads, Slope)*

Weighting and Integration of Data Sets

To determine the weightings of the various criteria, four factors of unequal importance were considered in the selection of waste transfer station sites. In this study, the focus was on the pairwise comparison method, which offers the additional benefits of providing a structured framework for group discussions and helping decision-making groups focus on areas of agreement and disagreement when determining the criteria weights. Saaty (1980) proposed the pairwise comparison method within the framework of the Analytic Hierarchy Process (AHP). According to Saaty, this method is an effective tool for determining relative importance (Saaty et al., 2022). It uses a ratio matrix to compare one criterion against another. Additionally, a numerical scale with varying values from 1 to 9, as shown in Table 2, is employed to assess the importance of each criterion.

Table 2: *Significance Weightage (Saaty et al., 2022)*

Importance Level	Definition (Verbal Judgement)
1	Equal importance
2	Between equal and moderate
3	Moderate importance
4	Between moderate and strong
5	Strong importance
6	Strong to very strong
7	Very strong importance
8	Very strong to exceptionally strong
9	Exceptional importance

Using the technique proposed by (Saaty et al., 2022), the weights were derived by normalizing the value of the pairwise comparison matrix. The consistency of the weights was then evaluated using Saaty's consistency ratio (CR), which provides a measure of deviation from consistency. Saaty suggested that if the CR exceeds 0.1, the matrix should be re-evaluated. To complete the pairwise comparison matrix, the authors referred to 5 experts in the Faculty of Engineering in Kabul University, who compared and assigned weights to the criteria.

Table 3: *Pairwise Comparison Matrix of Criteria*

	Criteria	(1)	(2)	(3)	(4)
1	Distance from main roads	1	2	3	3
2	Distance from residential areas	1/2	1	5	4
3	Distance from lakes/streams	1/3	1/5	1	2
4	Slope or gradient	1/3	1/4	1/2	1

As the pairwise comparison is completed by university lecturers, in the next step the numbers were normalized. In this process the assigned value was divided by sum of the column. In the next step, the sum and mean of each row were calculated. The geometric mean of the row in Table 4 shows the respective weightage of the criteria in the final suitability index.

Table 4: *Geometric Mean (Weight) for Criteria*

	Criteria	(1)	(2)	(3)	(4)	Sum of Each Row	Geometric Mean (Weight)
1	Distance from main roads	0.462	0.58	0.316	0.3	1.658	0.414
2	Distance from residential areas	0.230	0.298	0.526	0.4	1.454	0.364
3	Distance from lakes/streams	0.154	0.058	0.105	0.25	0.567	0.142
4	Slope or gradient	0.154	0.072	0.052	0.1	0.378	0.095

Once the weights were calculated, the next step was to combine all the weighted criteria to generate a suitability map. In this study, after calculating the weights, the consistency ratio (CR) was estimated to be 8.8%, which is less than the maximum 10% threshold suggested by Saaty (Saaty et al., 2022) and thus considered acceptable. Consequently, there was no need to re-evaluate the matrix.

The Weighted Linear Combination (WLC) method was employed to integrate individual criteria-based maps. The suitability index (SI) is calculated by multiplying the relative importance (weight) of each criterion by its standard suitability score and then summing the results using the following equation:

$$SI = \sum w_i s_i$$

Where: SI is the suitability index, w_i is the relative importance of criterion, S_i is the standard suitability score of criteria.

During the application of the WLC method, an evaluation scale is set. A scale of 1-3, as used in the reclassification of the data sets, is applied here as well. Since the data sets were classified into three classes, it is important to maintain the same scale and range for consistency.

FINDINGS

The methodology applied in this study generated suitability maps for each criterion—main roads, residential areas, lakes/streams, and slope—categorizing land into less suitable, suitable, and highly suitable classes for locating waste transfer stations. The total land area analyzed covers approximately 103,000 hectares across Kabul's 22 districts.

Integrated Suitability Analysis

Table 6 below summarizes the combined suitability based on a Weighted Linear Combination (WLC) method, which incorporated AHP-derived weights to integrate the individual criteria. This approach multiplies each criterion's standardized suitability by its relative weight and sums the results, creating a composite suitability index (SI). The consistency of weighting was confirmed with a CR of 0.08, meeting (Saaty et al., 2022) threshold.

This integrated suitability map shown in Figure 6 reveals that only about 18% of Kabul's land is highly suitable when balancing all factors, highlighting the trade-offs planners must consider. The large suitable class (47%) offers flexibility but may require mitigation strategies, while the less suitable areas (35%) suggest regions where development of transfer stations is inadvisable due to combined constraints.

***Table 1**: Classification of Kabul Lands based on the Integrated Suitability for Siting Transfer Stations*

Suitability Level	Highly Suitable (%)	Highly Suitable (Ha)	Suitable (%)	Suitable (Ha)	Less Suitable (%)	Less Suitable (Ha)
Area/Share	18.16	18697.41	47.03	48410.13	34.81	35833.91

The map shows that mostly the highly suitable areas locates outside the existing city fabric which have lower population density but are located near the highways. However, thinking practically, siting transfer stations in those areas would not be beneficial as it would reduce the efficiency in reducing the transport milage.

Table 5. *Suitability Classification Based on the Defined Criteria*

Criteria	Highly Suitable (%)	Highly Suitable (Ha)	Suitable (%)	Suitable (Ha)	Less Suitable (%)	Less Suitable (Ha)
Main Roads	41.93	43,193.53	16.72	17,223.44	41.35	42,591.04
Residential Areas	12.77	13,155.61	36.73	37,841.92	50.50	52, 024.50
Lakes/Streams	17.48	18,010.21	52.15	53,721.37	30.37	31,285.26
Slope	67.98	70,041.13	6.27	6,457.46	25.75	26,533.89

The data shown in Table 5 summarizes the suitability classification for each criterion, indicating the percentage of land area that falls into each category (highly suitable, suitable, and less suitable) for the establishment of waste transfer stations.

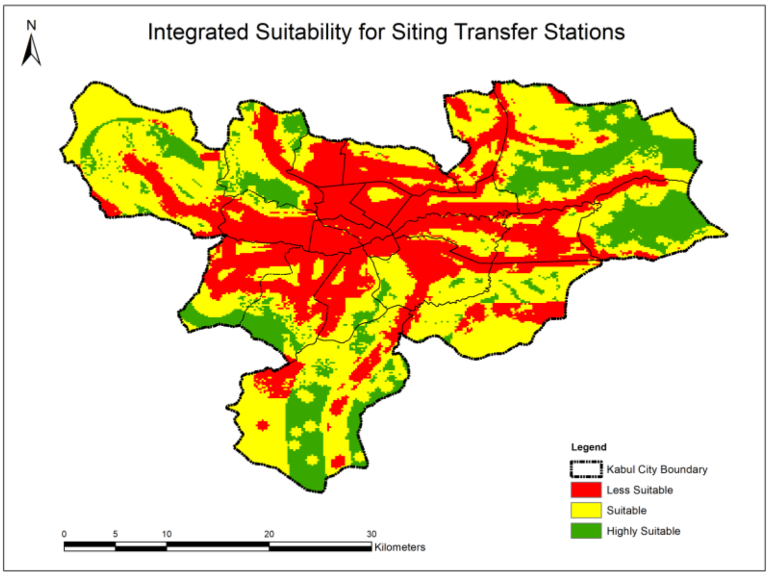

Figure 7. *Integrated Suitability Map for Siting Transfer Stations, Kabul City*

Distance from Main Roads. As can be observed in Figure6, a great portion of land (41.93%) is calculated to be highly suitable for waste transfer stations due to the need for proximity to major roads, and with 16.72% classified as suitable. It also shows a considerable portion of (41.35%) classified as less suitable, which may be due to the lack of road network in hilly areas of the city.

Distance from Residential Areas. Half of the land (50.50%) falls into the less suitable category due to proximity to dense residential zones, underscoring the need to minimize negative impacts such as odors, noise, and traffic congestion near communities. Only 12.77% of the land is highly suitable, suggesting limited buffer zones are available for waste infrastructure in urban neighborhoods. Constraints such as environmental pollution (leachate and odor), noise pollution from garbage trucks, impact on property prices, and psychological and social resistance of residents are among the factors that can influence the decision to locate transfer stations.

Proximity to Lakes and Streams. The majority (52.15%) of land is moderately suitable when considering protection of water bodies. The 30.37% classified as less suitable reflects mandatory setbacks to prevent water resource pollution, increased health risks, opposition to environmental regulations, and soil erosion and land instability, which directly influence siting decisions.

Slope. The largest share of Kabul's land (67.98%) is highly suitable based on slope criteria, indicating predominantly flat terrain favorable for construction and operational efficiency. The 25.75% less suitable land reflects steeper slopes where infrastructure development would be more costly and potentially unstable, suggesting slope is a significant physical constraint.

These results highlight the geographical constraints and opportunities for placing transfer stations based on environmental and infrastructural factors. The most prominent criteria as also can be observed in Figure 6, is location of main roads followed by distance from residential areas. These are justifiable because heavier weight was assigned to these criteria by the experts in pairwise comparison. Areas near main roads and residential zones show significant variation in suitability, with many residential areas being less suitable due to urban density and proximity to other critical land uses. Although the weightage of slope and distance from water bodies is lower, they influence the siting as if we compare the suitability map with the slope map, those areas with steeper slopes are less suitable for establishing transfer stations.

Assessment of KUDF Proposed Transfer Stations

The next step involved comparing the KUDF-proposed locations with the integrated suitability map generated through criteria evaluation. As shown in the Figure 8 below, six out of nine proposed sites fall within highly suitable or suitable areas. However, the remaining three locations are situated in less suitable zones and warrant further investigation before proceeding with development.

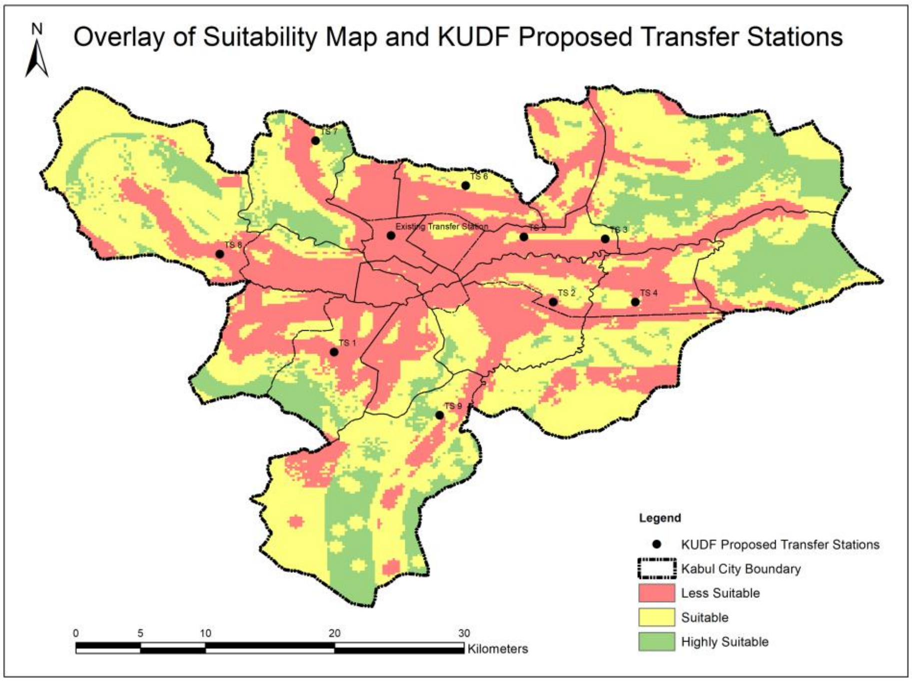

Figure 8. *Overlay of Suitability Map and Locations Proposed by KUDF*

DISCUSSION

This study applied a GIS-based Multi-Criteria Decision Analysis (MCDA) framework—integrating the Analytic Hierarchy Process (AHP) and Weighted Linear Combination (WLC)—to identify optimal locations for municipal solid waste transfer stations in Kabul. While the Kabul Urban Design Framework (KUDF) proposed the development of such facilities in 2018, no stations have yet been implemented. Among the contributing factors is the uncertainty among municipal stakeholders regarding whether the proposed locations were technically and environmentally appropriate. This hesitation has exacerbated inefficiencies in the current waste management system and contributed to lost opportunities for material recovery, especially among informal recyclers.

The findings indicate that only 18.16% of Kabul's land is highly suitable for transfer stations, with slope and proximity to main roads emerging as the most influential siting factors. The terrain offers limited options for flat and accessible parcels that can support high-volume, mechanized operations while minimizing haulage time and costs. In contrast, proximity to residential areas and water bodies acted as key constraints, reinforcing the need for environmental protection and community health safeguards in facility placement.

These spatial insights are highly relevant when contextualized with operational audits from the Gazak 2 landfill, where mixed waste streams—especially organics and plastics—have reduced the efficiency of both formal and informal recycling efforts. According to NEPA (2019) cited in Nikzad (2020), over 32% of waste at the site is organic, and informal recyclers often cannot recover high-value materials because they are contaminated during transport. The absence of strategically placed transfer stations not only increases travel distance and costs but also limits the effectiveness of early-stage sorting, which is crucial for increasing material recovery rates and reducing landfill dependency.

From a policy implementation perspective, the analysis shows that six out of nine KUDF-proposed station sites fall within highly or moderately suitable zones, providing validation for a majority of the original planning proposals. However, three proposed stations, including one near Qargha Dam, are located in environmentally sensitive or logistically challenging areas and therefore warrant further review before development. The spatial evidence produced by this study helps reduce institutional uncertainty and offers a more objective basis for advancing stalled infrastructure investments.

Compared to similar GIS-based MCDA studies in cities such as Tehran (Rafiee et al., 2011), Isfahan (Gbanie et al., 2013), and Nanjing (Cheng & Hu, 2010), this research reaffirms the importance of slope and road accessibility as key siting criteria. Yet, Kabul's context is distinct, characterized by fragmented institutional capacity, fragile governance, and limited availability of current spatial data. This study makes a practical contribution by integrating national-level urban planning frameworks with spatial analysis tools, helping bridge the implementation gap that persists in many post-conflict or resource-constrained cities. The methodological contribution also lies in successfully adapting the AHP-WLC model to a low-data environment and producing a replicable spatial decision support tool tailored to real-world institutional challenges. The study demonstrates that even in fragile urban settings, structured and evidence-based methods can be employed to guide infrastructure decisions, reduce planning paralysis, and unlock sustainable development outcomes.

Beyond logistics, this study also underscores the social and economic benefits of improved transfer station planning. Increased access for informal recyclers at well-placed stations could enable greater volumes of material recovery, job creation, and cost savings for the municipality. For example, earlier separation of food waste for use as livestock fodder or biogas could reduce landfill volumes by up to 40%, while expanded recovery of plastic and paper supports local industries and contributes to circular economy goals.

From a methodological standpoint, the integration of AHP and WLC within a GIS framework proved highly effective in addressing Kabul's unique combination of topographical, infrastructural, and social constraints. The consistency ratio (CR = 0.088) indicated reliable expert judgment, and the use of standardized raster analysis enabled a spatially explicit view of suitability that can be directly incorporated into urban development plans.

Nonetheless, several limitations must be acknowledged. The study did not incorporate dynamic waste flow data, soil structure, detailed land tenure conditions, or socio-political barriers, all of which may influence the practical feasibility of site development. Furthermore, the number of experts involved in AHP weighting was limited, potentially introducing subjectivity despite acceptable consistency levels. Finally, the analysis did not include participatory components, such as community consultations or social impact assessments, which would be essential for the inclusive implementation of waste infrastructure in Kabul.

In a nutshell, this research contributes new empirical and spatial evidence to a long-standing policy implementation gap. It not only confirms the partial alignment of the KUDF's proposals with technical suitability but also highlights the broader significance of transfer station development for environmental management, informal labor integration, and long-term urban sustainability.

CONCLUSION

This study tackled a critical infrastructure and policy gap in Kabul by identifying optimal locations for municipal solid waste transfer stations using a GIS-based Multi-Criteria Decision Analysis (MCDA) framework. By integrating the Analytic Hierarchy Process (AHP) and Weighted Linear Combination (WLC), the research produced a spatially explicit suitability map that reflects Kabul's unique geographic, infrastructural, and environmental conditions.

The analysis revealed that only 18.16% of Kabul's land is highly suitable for transfer stations, with slope and proximity to main roads emerging as the most influential criteria. While six out of nine proposed sites from the Kabul Urban Design Framework (KUDF) were found to be technically viable, three require reassessment due to environmental sensitivity or infrastructure constraints. This evidence-based validation helps reduce the uncertainty that has delayed implementation since KUDF's adoption in 2018.

Beyond logistics, this research emphasizes the broader implications of inadequate transfer station infrastructure. Operational data from the Gazak 2 landfill show that significant volumes of recyclable and organic materials are lost due to contamination during long-haul transport. This limits the ability of informal recyclers—who play a key role in Kabul's waste recovery ecosystem—to retrieve value from the waste stream. As a result, both material recovery and job creation opportunities are undermined, while the volume of waste reaching the landfill remains unnecessarily high.

By spatially validating where transfer stations could be most effectively established, this study offers a replicable and policy-relevant planning tool. It supports more confident investment by municipal authorities, while also providing a technical foundation for further feasibility and design studies.

However, several limitations must be acknowledged. These include limited access to real-time waste flow data, exclusion of land tenure and cost-benefit considerations, and a relatively small pool of expert participants for the AHP weighting process. These constraints suggest that future research should incorporate economic analyses, social acceptance studies, and stakeholder consultations, as well as environmental impact assessments (EIAs) for each potential site.

Considering the findings, the following recommendations are proposed:

- Undertake detailed site-level technical assessments and engineering designs for priority stations.
- Conduct social and environmental impact assessments to ensure community acceptance and sustainability.
- Enable informal recyclers to operate at future transfer stations through policy support and infrastructure access.
- Explore at-source waste separation schemes and localized recycling initiatives simultaneously with infrastructure development.

Ultimately, this study contributes to narrowing the gap between urban planning and implementation in fragile urban contexts by providing a GIS-based methodological framework tailored to Kabul's conditions. It delivers practical insights that can inform the development of more efficient and context-sensitive solid waste management infrastructure in Kabul and presents a replicable approach that may be adapted for other rapidly urbanizing cities facing comparable challenges.

AUTHORS CONTRIBUTIONS

- Mohammad Kamil Halimee conceptualized and supervised the study, developed maps, edited and finalized the manuscript.
- Mohammad Seddiq Sadeq supported the conceptualization of the study and wrote the initial manuscript.
- Ali Kaihan Stanikzai investigated and analyzed data, supported writing the initial manuscript.
- Sayed Murtaza developed supported development of the maps, validated data, and supported review of the manuscript.
- All authors reviewed and approved the final version.

ACKNOWLEDGEMENTS

We extend our sincere appreciation to all those who contributed to the study. Dr. Saraj Sharifzai, Ahmad Rasa Arsalan, Bezhan Safi, Mohammad Akram, and Khwaja Jamil lecturers in Faculty of Engineering supported the weighting criteria. In addition, sincere gratitude to Mr. Ghulam Rabani, the Admin Officer in the Sanitation Department of Kabul Municipality who has generously provided information about waste collection and transfer stations.

FUNDING INFORMATION

No funding was available for the study.

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflict of interest.

DATA AVAILABILITY STATEMENT

All data generated or analyzed during this study are available on request.

REFERENCES

Ahmadi, H., Popalzai, A., Bekbotayeva, A., Omarova, G., Assubayeva, S., Arshamov, Y., & Pekkan, E. (2024). Assessing the Impacts of Landuse-Landcover (LULC) Dynamics on Groundwater Depletion in Kabul, Afghanistan's Capital (2000–2022): A Geospatial Technology-Driven Investigation. *Geosciences*, *14*(5), Article 5. https://doi.org/10.3390/geosciences14050132

Azimi, A. N., Dente, S. M. R., & Hashimoto, S. (2020). Social Life-Cycle Assessment of Household Waste Management System in Kabul City. *Sustainability*, *12*(8), 3217. https://doi.org/10.3390/su12083217

Bovea, M. D., & Powell, J. C. (2006). Alternative scenarios to meet the demands of sustainable waste management. *Journal of Environmental Management*, *79*(2), 115–132. https://doi.org/10.1016/j.jenvman.2005.06.005

Chirico, P. G., & Barrios, B. (2005). Void-Filled SRTM Digital Elevation Model of Afghanistan. In *Data Series* (No. 130). U.S. Geological Survey. https://doi.org/10.3133/ds130

Forouhar, A., & Hristovski, K. D. (2012). Characterization of the municipal solid waste stream in Kabul, Afghanistan. *Habitat International*, *36*(3), 406–413. https://doi.org/10.1016/j.habitatint.2011.12.024

Geofabrik Download Server. (n.d.). Retrieved June 24, 2025, from https://download.geofabrik.de/

Kaza, S., Lisa Yao, Perinaz Bhada-Tata, & Frank Van Woerden. (2018). *What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050*. World Bank.

Khoshbeen, A. R., Logan, M., & Visvanathan, C. (2020). Integrated solid-waste management for Kabul city, Afghanistan. *Journal of Material Cycles and Waste Management*, *22*(1), 240–253. https://doi.org/10.1007/s10163-019-00936-z

Komilis, D. P. (2008). Conceptual modeling to optimize the haul and transfer of municipal solid waste. *Waste Management*, *28*(11), 2355–2365. https://doi.org/10.1016/j.wasman.2007.11.004

MUDL & Sassaki. (2018). *Kabul Urban Design Framework*. Ministry of Urban Development and Land, Afghanistan.

Nikzad, H. (2020). Solid Waste Management in Kabul. In S. K. Ghosh (Ed.), *Circular Economy: Global Perspective* (pp. 43–65). Springer Singapore. https://doi.org/10.1007/978-981-15-1052-6_3

NSIA. (2024). *Estimated Population of Afghanistan 2024-25*. National Statistics and Information Authority.

Rafiee, R., Khorasani, N., Mahiny, A. S., Darvishsefat, A. A., Danekar, A., & Hasan, S. E. (2011). Siting Transfer Stations for Municipal Solid Waste Using a Spatial Multi-Criteria Analysis. *Environmental & Engineering Geoscience*, *17*(2), 143–154. https://doi.org/10.2113/gseegeosci.17.2.143

Saaty, T., Vargas, L., & St, C. (2022). *The Analytic Hierarchy Process*.

Ullah, S., Bibi, S. D., Ali, S., Noman, M., Rukh, G., Nafees, M. A., Bibi, H., Ali, S., Qiao, X. C., Khan, S., & Hamidova, E. (2022). Analysis of Municipal Solid Waste Management in Afghanistan, Current and Future Prospects: A Case Study of Kabul City. *Applied Ecology and Environmental Research*, *20*(3), 2485–2507. https://doi.org/10.15666/aeer/2003_24852507

US EPA, O. (2002). *Waste Transfer Stations: A Manual for Decision-Making* [Overviews and Factsheets]. https://www.epa.gov/landfills/waste-transfer-stations-manual-decision-making

Zamorano, M., Molero, E., Grindlay, A., Rodríguez, M. L., Hurtado, A., & Calvo, F. J. (2009). A planning scenario for the application of geographical information systems in municipal waste collection: A case of Churriana de la Vega (Granada, Spain). *Resources, Conservation and Recycling*, *54*(2), 123–133. https://doi.org/10.1016/j.resconrec.2009.07.001