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RESEARCH ARTICLE

Spatial Evaluation of Waste Disposal Site Selection Using Gis-Based2 Multi-Criteria Analysis: A Case Study of Dera Ghazi Khan District, Pakistan

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Abstract The rapid population growth and rising per capita incomes have caused the city to generate massive amounts of municipal waste, indicating a serious environmental threat. Solid waste disposal has become a crucial problem for several municipalities. The selection of suitable waste disposal sites is a crucial problem in the urban areas of developing countries like Pakistan due to unsatisfactory urban planning and management to decrease human being's health risks. Particularly, Dera Ghazi (D.G.) Khan district is facing the issue of identifying suitable sites for solid waste disposal. This research aims to select appropriate potential sites suitable for solid waste disposal purposes in the D.G. Khan. Primary datasets used for this study are Landsat-8 satellite imagery, digital elevation model (DEM) with 30-meter resolution for slope extraction. Other criteria included roads, railroads, and rivers digitized using the topographical map of the study area. The maps are prepared to incorporate overlay and suitability analysis using Geographic Information System (GIS), Remote Sensing techniques, and Analytical Hierarchy Process (AHP), a multi-criteria analysis. The final suitability map of study area is prepared using a GIS software suite and categorized as highly, moderately, least, and unsuitable regions, of which 3% is entirely unsuitable area, 70% less suitable, 26.16% moderately suitable, and 0.84% highly suitable area. The suggested disposal sites have been carefully selected to assist policymakers in determining the most sensitive areas and resolving waste management issues with the slightest contamination of water bodies and the environment.

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1. Introduction

Solid waste is a global environmental problem in today's world, both in underdeveloped and developed countries (Ngumom & Terseer, 2015). The rapid growth of the world's population, economy, and standard of living has accelerated solid waste generation, surpassing 6 million tons per year (El Maguiri et al., 2016; Shamshiry et al., 2013). According to World Bank (2012) predictions, global municipal waste production may increase by up to 70%. In just a decade, global municipal solid waste production rose from 0.68 billion tons per year (2000) to 1.3 billion tons per year (2010) and is expected to reach 2.2 billion tons per year in 2025 and 4.2 billion tons per year in 2050 (Yasin et al., 2017). Solid waste disposal is a critical component of waste management that requires special attention to minimize pollution and health risks. Unfortunately, most landfills are located on the outskirts of cities near water bodies, agricultural land, settlements, and roads. They often block drains and narrow streets, creating favorable conditions for the breeding of disease-carrying flies, mosquitoes, and rodents (Abul, 2010).

Pakistan, like other developing countries, faces serious environmental challenges, especially in waste disposal management in major cities. The absence of proper policies, financial support, conventional waste disposal systems, and inadequate waste control procedures contribute to the problem (Samiullah et al., 2016). The Pakistani Education Ministry reports that cities produce over 54,850 tons/day of waste, but due to mismanagement, only 50% is collected (Yasin et al., 2017). Urgent renovation is needed for the current waste management system. Despite allocating 20% to 40% of their budgets, municipalities have struggled to meet environmental quality standards (Khan, 1998). Landfilling remains Pakistan's most effective waste management method, but existing landfills are overcrowded, leading to severe impacts on nearby residential areas. Unplanned landfill placement has resulted in an unhealthy environment, poisoning both air and water supplies.

Dera Ghazi (D.G.) Khan is a densely populated district of Pakistan and produces much waste. According to integrated solid waste management (ISWM), D.G. Khan district has around 132.20 tonnes of municipal waste with an estimated annual volume of 48,253 tons. Current waste production is 0.4 kg/capita calculated with an increase of 1.5% annually (http://epd.punjab.gov.pk/?q=solid_waste). In D.G. Khan, pollution is caused by the garbage of houses and hospitals, factories, restaurants, and waste effluents in industrial water.

Today, D.G. Khan is threatened by unrestrained practices such as open dumps, fertilizer waste, pesticides, and unrestrained sewage systems.

Many waste management processes, including recycling, incineration, and landfill, are implemented in our surroundings. However, landfill stands out as a cost-effective and sustainable option for the environment. Geographic Information System (GIS) tools and techniques play a crucial role in making informed landfill selection decisions by processing accurate geospatial data from various sources. GIS-based analysis provides valuable insights and potential solutions to problems (Ahmad et al., 2016). This study used Multi-Criteria Analysis (MCA) and Analytical Hierarchy Process (AHP) through GIS to address landfill selection challenges successfully to saving both time and cost in site selection (Chabuk et al., 2017). Nonetheless, waste disposal and management pose a significant challenge involving decision-makers and relevant stakeholders (Guler & Yomralioglu, 2017).

In this context, our contribution combines GIS technology and MCA to find optimal landfill locations in the study area. GIS proves to be an excellent tool for management planning and analysis, aiding authorities in strategic decision-making regarding land use planning, urban planning, environmental protection, economic development, and so on (Mohammed et al., 2018; See et al., 2018; Zia et al., 2022). This study serves as methodological guidelines for selecting optimal landfills, considering land use/ land cover, physical, topographical and administrative dynamics. The study focuses on determining the main criteria for the location of landfills in the study area that meet the required standards and assessing and evaluating the land spatially for waste disposal purposes using geospatial data and tools.

2.1. Study area

D.G. Khan is a district in the Punjab province of Pakistan (figure 1). It is Pakistan's 19th largest city, in terms of population, located on the western bank of the Indus river, and covers an approximate area of 11,294 km^2. D.G. Khan district lies between the coordinates 30° 01' 59" N latitude and 70° 38' 24" E longitude. It is a mid-country city located at the junction of all four provinces of Pakistan. On the north side of this district, Suleiman mountains rise to a height of 10,000 feet. This indicates that the district is located near the foothills of Suleiman's mountain range and has some hills within the boundaries of D.G. Khan district. D.G. Khan has significant settlements with a population of more than 2,872,201 according to latest census report of 2017 of Pakistan Bureau of Statistics.

2. Materials And Methods

2.1. Materials

According to study of previous research, various landfill selection methods have been developed over the past few decades to improve waste disposal site selection efficiency. Since the landfill selection process relies on multiple rules, ordinances, aspects, and vast spatial data that should be evaluated and processed. GIS is widely utilized to choose the appropriate landfill site (Allen, 2002).

2.1.1. Multi-Criteria Analysis (MCA) using GIS:

Multi-Criteria Analysis (MCA) is employed to address complexities faced by decision-makers when dealing with vast and intricate information. The integration of GIS and MCA is crucial for landfill selection, offering digital geospatial data for long-term location monitoring (Mohammed et al., 2018). MCA technique contacts the decision-making process involving multiple criteria. However, determining weights for different factors based on their significance is a common challenge (Chitsazan et al., 2013). This method simplifies decision complexities by breaking them down into more manageable parts, individually analyzing each element, and then integrating them logically (Nas et al., 2010). MCA

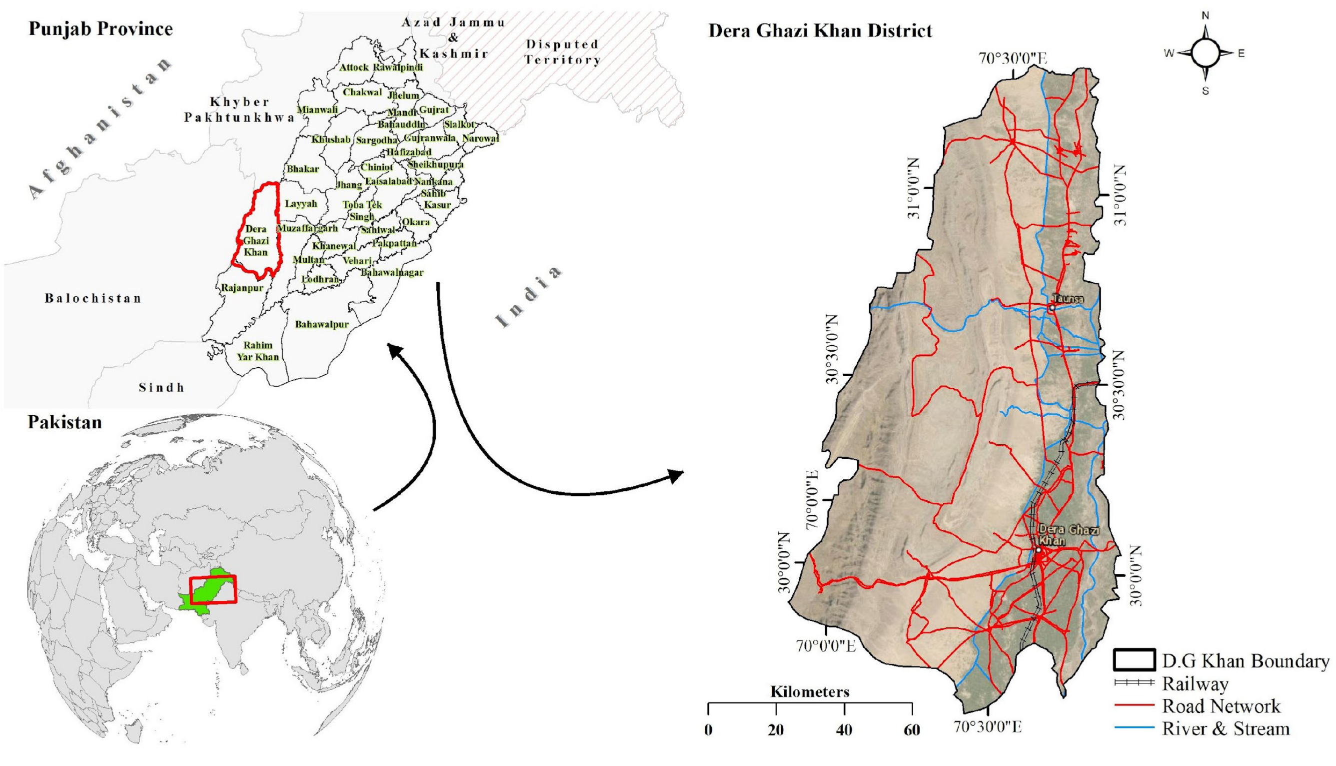

Figure 1. Study area map of Dera Ghazi Khan District, Punjab, Pakistan

ensures a consistent classification of potential landfill areas at the disposal site based on various criteria (Şener et al., 2006). Higgs (2006) recognized the potential of combining multi-criteria techniques with GIS at waste disposal facilities.

This study employs both primary and secondary data, including spatial and non-spatial information, supplemented by a comprehensive site survey based on several standard criteria. GIS is employed to exclude inappropriate areas using the Euclidean distance tool and creating buffers around the specified criteria which have vector data and transforming it into the raster format. To interpolate the underground water table, the Inverse Distance Weighted (IDW) interpolation tool is applied, generating a raster using measured values on specified locations to estimate nearby unmeasured locations. For topographical analysis, a Digital Elevation Model (DEM) of Shuttle Radar Topography Mission (SRTM) with a resolution of 30 meters is downloaded from United States Geological Survey (USGS) to establish slope criteria. The conceptual framework for the landfill site methodology is shown in figure 2.

2.1.2. Analytical Hierarchy Process (AHP) technique in GIS and Remote Sensing:

GIS is a valuable tool in environmental studies, enabling ecological and developmental management (Wang et al., 2009). GIS is a managing tool that finds applications in various disciplines, including environmental management, wildlife, agriculture, water management, and natural disaster estimation (Wang et al., 2009). Remote sensing, an allied GIS field, involves acquiring, measuring and analyzing data captured through sensors onboard satellite or other platforms. In waste disposal site selection, remote sensing efficiently utilizes satellite imagery to extract relevant criteria (Oštir et al., 2003). Additionally, remote sensing provides digital data input to GIS.

Saaty (1977) introduced the Analytical Hierarchy Process (AHP) as an approach to assign weights to criteria. AHP involves making paired comparisons between different elements, allowing researchers to distinguish the significance of criteria based on their preferences (Saaty, 2008). It serves as a reliable tool for decision-making and enhances the understanding of alternatives by arranging influencing criteria into manageable portions. Therefore, AHP distributes decision problems into manageable portions based on features, examining each part individually and combining them sensibly, as proposed by Dijkstra (2013). AHP utilizes a 9-point scale in the decision-making technique for selecting the disposal site (Saaty, 1980). These rankings are derived from various literature sources. For selecting criteria to be used in this study we reviewed multiple studies (table 1) to find most commonly used criteria.

2.2. Methodology

Landfill's selection comprises thorough evaluation process to identify the most accessible storage location using MCA process. GIS-based mapping is employed to eliminate ecologically unsuitable sites, reducing them for further assessment. Each criterion is divided into four classes: high suitable, moderately suitable, less suitable, and unsuitable, ranked from 1 to 4, with 4 indicating highly appropriate and 1 for inadequate areas (table 2). MCA assigned weights to arrange and classify the appropriate sites. The weights and rank for each class of every criterion are employed to

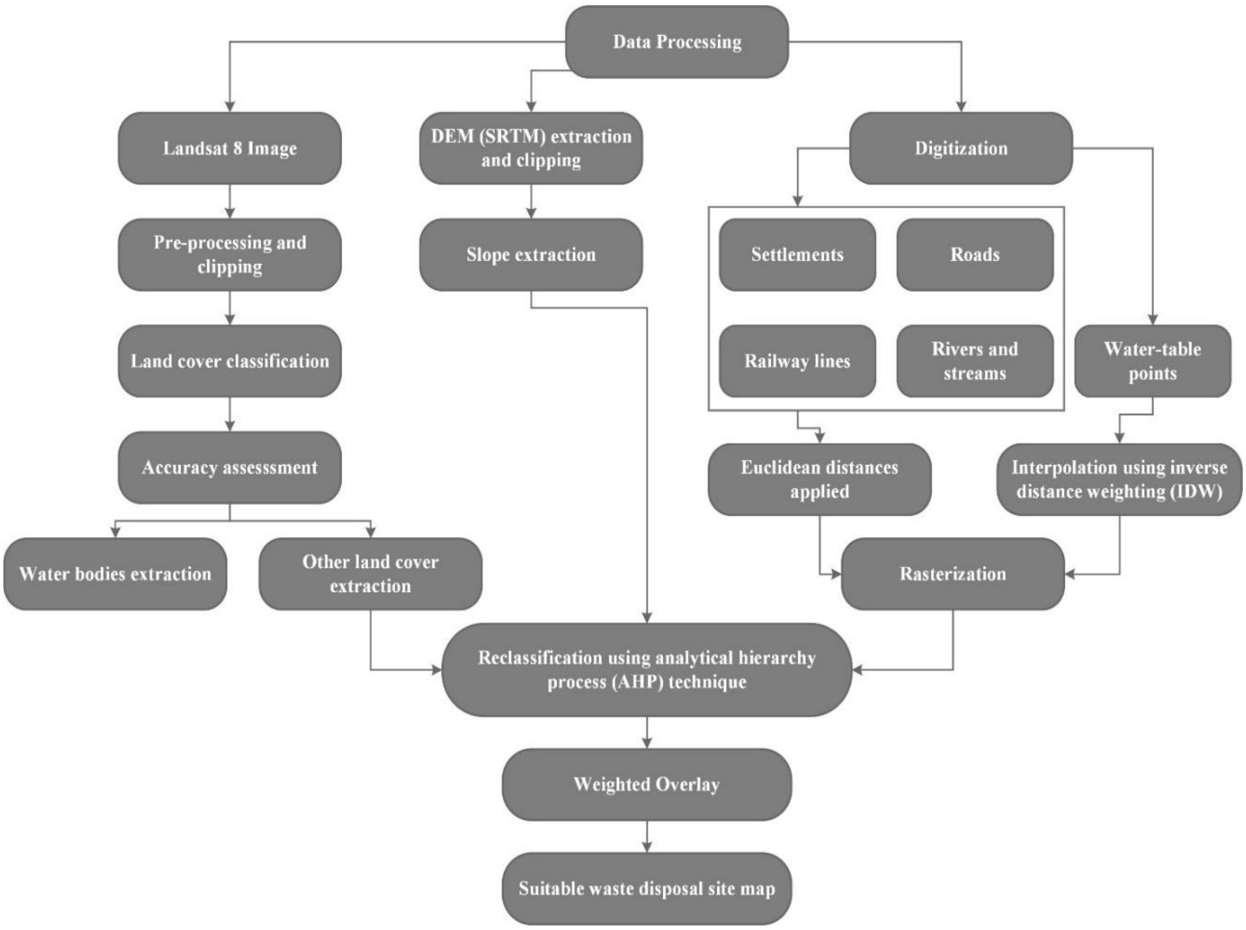

Figure 2. Flow Chart of Methodology Workflow of Landfill Site Selection

respective spatial data using Arc-GIS 10.4.1 Software in two steps through AHP, relying on expert preferences to compare classes and create numerical matrices. Figure 2 illustrates the methodological flow chart depicting the techniques and methods used to identify suitable landfill locations.

Landsat-8 satellite imagery is used to create land use/ land cover map of the entire study area. After pre-processing, Landsat-8 imagery is classified using supervised classification technique. The classification toolbar is employed to generate training samples, which helped characterize the classes by utilizing concerning areas and extracting similar classes from another region. A signature file is created from these training samples and utilized in supervised classification technique to reclassify the imagery based on the maximum likelihood algorithm. In the end, land use/land cover maps are then divided into five feature classes: agricultural land, barren land, water bodies, built-up area, and rocky region.

Table 1. Previous studies about the AHP technique

Study reference	Number of criteria	Study area	Study area coverage	Suitable sites identified	Multi-criteria method used
(Alkaradaghi et al., 2019)	13	Sulaimaniyah Governorate, Iraq	2,400 km^2	1,920 km^2	AHP
	15	Al-Qasim Qadhaa, Iraq	637 km^2	4.82 km^2	AHP
(Chabuk et al., 2016)	6	Sahiwal, Pakistan	1,160 km^2	3 sites	AHP
	8	Asaita Town, Ethiopia	59.87 km^2	2.99 km^2	AHP
(Ahmad et al., 2016)	9	Bahir Dar Town, Ethiopia	212.81 km^2	25.28 km^2	AHP
	16	Middle East	603 km^2	57.89 km^2	AHP
(Aden, 2016)	17	Al-Najaf Governorate, Iraq	28,824 km^2	1,268.3 km^2	AHP
	11	Varanasi city, India	112.26 km^2	5.73 km^2	AHP
(Ebistu & Sewnet Minale, 2013)	10	Senirkent–Uluborlu, Turkey	753 km^2	15.81 km^2	AHP
	8	Nevesinje, Serbian	923.4 km^2	92.34 km^2	AHP

Table 2. Reclassify Ranges for suitable waste disposal site selection factors

Sr. No.	Name of criteria	Classes	Ranking	Reference
1	River and Stream network	0-1 km 1 km - 3 km 3 km - 6 km >6 km	1 2 3 4	(Ahmad et al., 2016; Chabuk et al., 2016; Ebistu & Sewnet Minale, 2013; Ohri et al., 2015; Şener et al., 2011; Yildirim, 2012)
2	Road Network	0-1 km 1 km - 3 km 3 km - 5 km >5 km	1 4 3 2	
3	Railway Line	0-1 km 1 km - 2 km 2 km - 3 km >3 km	1 2 3 4	(Chabuk et al., 2016; Ebistu & Sewnet Minale, 2013; Ohri et al., 2015)
4	Settlements	0-1 km 1 km - 2 km 2 km - 2.5 km >2.5 km	1 2 3 4	
5	Slope	0-10 % 10 - 25% 25 - 45% >45%	1 4 3 2	(Chabuk et al., 2016)
6	Water Table	0-20 m 20 - 30 m 30 - 40 m >40 m	1 2 3 4	
7	Land use- Landcover	Agricultural Land Built-up Area Water Bodies Rocky Region Barren land	1 1 1 1 4	(Ebistu & Sewnet Minale, 2013; Ohri et al., 2015)

Several criteria decision-making literature proposes various criteria weighting methods depending on the decision maker's judgment. One of the best method is pair-to-pair comparison, developed as part of the AHP decision-making procedure. In weighted linear combination methods for multiple criteria assessment, the sum of weights must be 1. Through literature review, we have determined the researcher's suggestions for creating correlation with other criteria as shown in table 3.

AHP uses the principal eigenvector of a reciprocal square matrix from pair-wise comparisons between criteria to find weights. These comparisons determine the comparative significance of two criteria that are involved at same time in determining the adequacy with defined objective. All probable combinations of two aspects are compared depending on professional experts' decisions to create a paired comparison matrix from which module then computes a series of weights and a consistency ratio.

2.2.1. Pair-wise comparison weight calculation:

Relative weights of substitutes are calculated against each respective selection criteria to determine the value of a landfill site. Table 4 below lists the seven calculated criteria. Pair-wise comparisons are conducted for each criterion layer to assess the potential of the locations for waste disposal site qualification.

The consistency index (CI) and consistency ratio (C.R.) for the substitutes against each criterion are computed, ensuring the acceptability of the pair-wise comparison analysis of alternatives. C.R. = 0.00 means that the judgements have no limit of consistency (Satty, 1977). The total relative weights of substitutes for every selected criterion (Table 4) are calculated according to the criteria of landfill site. The composite's total weight is obtained by combining alternative relative weights with the selection criteria weights, resulting in an appropriate index.

3. Results:

Seven criteria are utilized to select a suitable disposal site in D.G. Khan District. Among them, four criteria (roads network, railway tracks, settlements, rivers, and stream network) required to calculate buffer distance to estimate the limitation with multi-relationship buffer tool and reclassification for simplification. Once the above procedures are completed, the suitable range is defined according to the appropriate standard of buffer distance range for landfill site selection (figure 3). All criteria are reclassified and assigned a suitability range according to their weight, influencing the site selection process. When assigning compatible range values, values 1, 2, 3, and 4 indicate that the selected range is unsuitable, least suitable, moderately suitable, and highly suitable respectively.

Table 3. Researchers' suggestions for criteria weights in AHP techniques

Sr. No.	Name of criteria	Researcher's suggestions for creating correlation with other criteria
1	Settlements	(Al-Anbari et al., 2016; Alkaradaghi et al., 2019; Chabuk et al., 2016; Şener et al., 2006)
2	River and Stream	
3	Road Network	(Aden, 2016; Alkaradaghi et al., 2019; Getahun, 2020; Şener et al., 2006; Şener et al., 2011)
4	Water Table	
5	Land use- Landcover	(Ahmad et al., 2016; Al-Anbari et al., 2016; Ebistu & Sewnet Minale, 2013; Getahun, 2020; Ohri et al., 2015)
6	Slope	
7	Railway Line	(Ohri et al., 2015; Şener et al., 2006; Şener et al., 2011)

Table 4. Pair wise Comparison Method for Landfill Site through AHP Technique

Paired comparison (AHP)	Settlements	River & streams	Road network	Water table	LU & LC	Slope	Railway	Nth root	PV
Settlements	1	3	6	4	5	6	9	2.62	0.37
River & streams	0.33	1	5	7	6	5	7	1.98	0.28
Road network	0.16	0.2	1	2	2	4	5	0.77	0.11
Water table	0.25	0.14	0.5	1	3	4	5	0.75	0.11
LU & LC	0.2	0.16	0.5	0.33	1	2	4	0.45	0.06
Slope	0.12	0.2	0.25	0.2	0.2	1	3	0.27	0.04
Railway	0.11	0.12	0.2	0.2	0.25	0.33	1	0.16	0.02
SUM								7	1
SUM	2.17	4.82	13.45	14.73	17.45	22.33	34		
Lambda max	7.38								
CI	0.063								
CR	0.048								

3.1. Description of criteria used

This study contains seven distinct criteria, each representing different aspects such as slope (topographical factor), water table, land use, and rivers (environmental impacts), and railway, road network, and settlements (ecological factors). These criteria are crucial in identifying the appropriate landfill site. Throughout this process, particular attention is paid to prevent any adverse environmental effects.

3.1.1. River and streams network

Water bodies specifically require attention for finding appropriate landfill site. Because the criteria state that water surfaces like dams or rivers should be far away from selected area, establishing a nearby landfill can negatively impact water quality.

To decrease susceptibility of groundwater and surface water contamination, landfills should be located away from rivers. During this study, Euclidean distance tool is employed to create buffers of over 1 km from the boundaries of rivers and streams, protecting them from potential contamination (figure 3a). The buffer distances are categorized into four classes: 0-1 km, 1-3 km, 3-6 km, and more than 6 km. These buffer zones are then reclassified and ranked as unsuitable (rank 1), least suitable (rank 2), moderately suitable (rank 3), and highly suitable (rank 4) areas for landfill selection.

3.1.2. Road network

According to economic and social perspectives, road network is a most significant criterion for landfill selection (Alkaradaghi et al., 2019). Landfills located too close to roads can create public health issues. Moreover, a landfill that very distant from the road is not recommended due to high transportation expenses (Al-Anbari et al., 2016). However, the appropriate landfill site should be at a considerable distance from main roads but not isolated. Euclidean distance tool generates buffer values, which are ranked as follows: 0-1 km (rank 1), 1-3 km (rank 4), 3-5 km (rank 3), and more than 5 km (rank 2) as shown in figure 3b.

3.1.3. Railway track

Railways, like roads, serve as transportation routes, making this criterion equally important. However, railways differ from roads in that they are not used to transfer waste material from public points to landfill sites (Chabuk et al., 2016). Constructing a landfill near a railway track or junction can pose hazards and nuisances to travelers due to unpleasant odors and pollution. In this study, Euclidean distance tool is also utilized to create buffer values, resulting in the following ranks: 0-1 km (rank 1), 1-2 km (rank 2), 2-3 km (rank 3), and more than 3 km (rank 4) as shown in figure 3c.

3.1.4. Settlement

The settlement area is a significant environmental feature encompassing various services in the study area, such as built-up areas, commercial zones, holy places, educational institutions, clinics, hospitals, private organizations, and social service areas. To promote a sustainable atmosphere, special consideration must be given to the surrounding environment, particularly settlements. To prevent adverse impacts, landfill sites have been strictly prohibited in all settlement areas.

For this criterion, the Euclidean distance tool is employed once again to create buffer values, and suitability ranks are assigned based on the following ranges: 0-1 km (rank 1), 1-2 km (rank 2), 2-2.5 km (rank 3), and more than 2.5 km (rank 4) as shown in figure 4d.

3.1.5. Land use/ land cover pattern

Land use/ land cover is a critical criterion used to create a map of potential waste disposal sites in D.G. Khan District. The entire eastern portion of this district is mainly agricultural land with settlements along its boundary (figure 4a). Central region contains a lot of barren land and some settlements, while the western part is entirely rocky terrain. Although the rocky terrain may be suitable for solid waste disposal, it is too distant from settlement areas where most waste is generated. As a result, landfill's locations are limited to areas with predominantly agricultural land and settlement regions.

Land use/ land cover map of the study area is shown in figure 4a. Further reclassification, based on rankings, of these land use/ land cover into two classes is carried out, with ranks 1 assigned to unsuitable (other than barren class) and ranks 4 to highly suitable (barren class) classes as shown in figure 4b.

3.1.6. Slope

The slope's map reveals that the western part of the district is rocky with a high slope on the northern side. But central part consists of barren land, while the southwest part has an approximately gentle and reasonable slope. Slope is most important parameter considered in landfill selection (Şener et al., 2006). In this study, slope areas are computed in a GIS environment using USGS STRM DEM with 30 -meter spatial resolution. Areas with extreme elevations or steep slopes are not suitable for waste disposal site. The finest waste disposal site are medium-height sites surrounded by slopes of at most 25%. While the literature review classifies land into three slope classes (0–10%, 10–20%, and more than 20%) for the slope criterion (Akbari et al., 2008), this study reclassifies the slope into four classes and assigns rankings: 0-10% (rank 1), 10-25% (rank 4), 25-45% (rank 3), and above 45% elevation (rank 2) as shown in figure 4c.

3.1.7. Water table

A water-table layer is prepared to depict the overall pattern of entire district as shown in figure 4d. The map displays that water-table on eastern side, particularly near the rivers, is shallow. On the other hand, the western side of the district had a low water-table. Shallow water-table regions are unsuitable for landfills, which is why these areas are assigned the lowest values. Disposing waste material near water bodies can lead to severe health complications with lasting effects on animals and humans, as water is a vital natural element used for various purposes.

The contiguity of solid waste discharge point to a groundwater source is a significant environmental consideration in selecting the discharge point. So that the water table can be secured against overflow and ejection from waste disposal point (Ohri et al., 2015). Therefore, waste disposal in such areas having extremely deep groundwater depths may be appropriate. In this study, we applied IDW interpolation tool to generate a continuous water table map of the study area. The resulting values from the interpolation are classified into four classes.

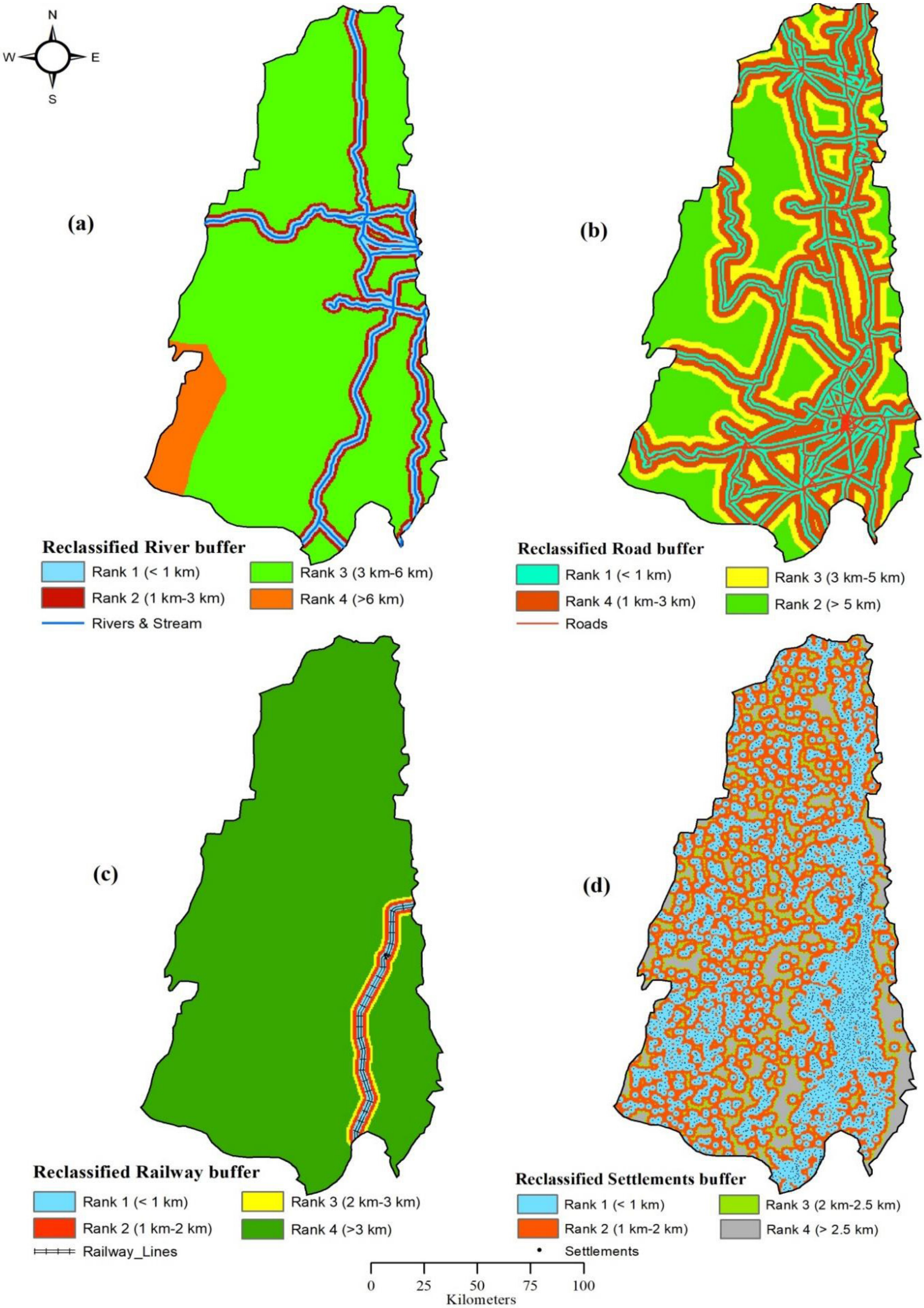

Figure 3. (a) Reclassified raster map for river buffer based on AHP ranking (b) reclassified raster map for road buffer based on AHP ranking (c) reclassified raster map for railway buffer based on AHP ranking (d) reclassified raster map for settlements buffer based on AHP ranking

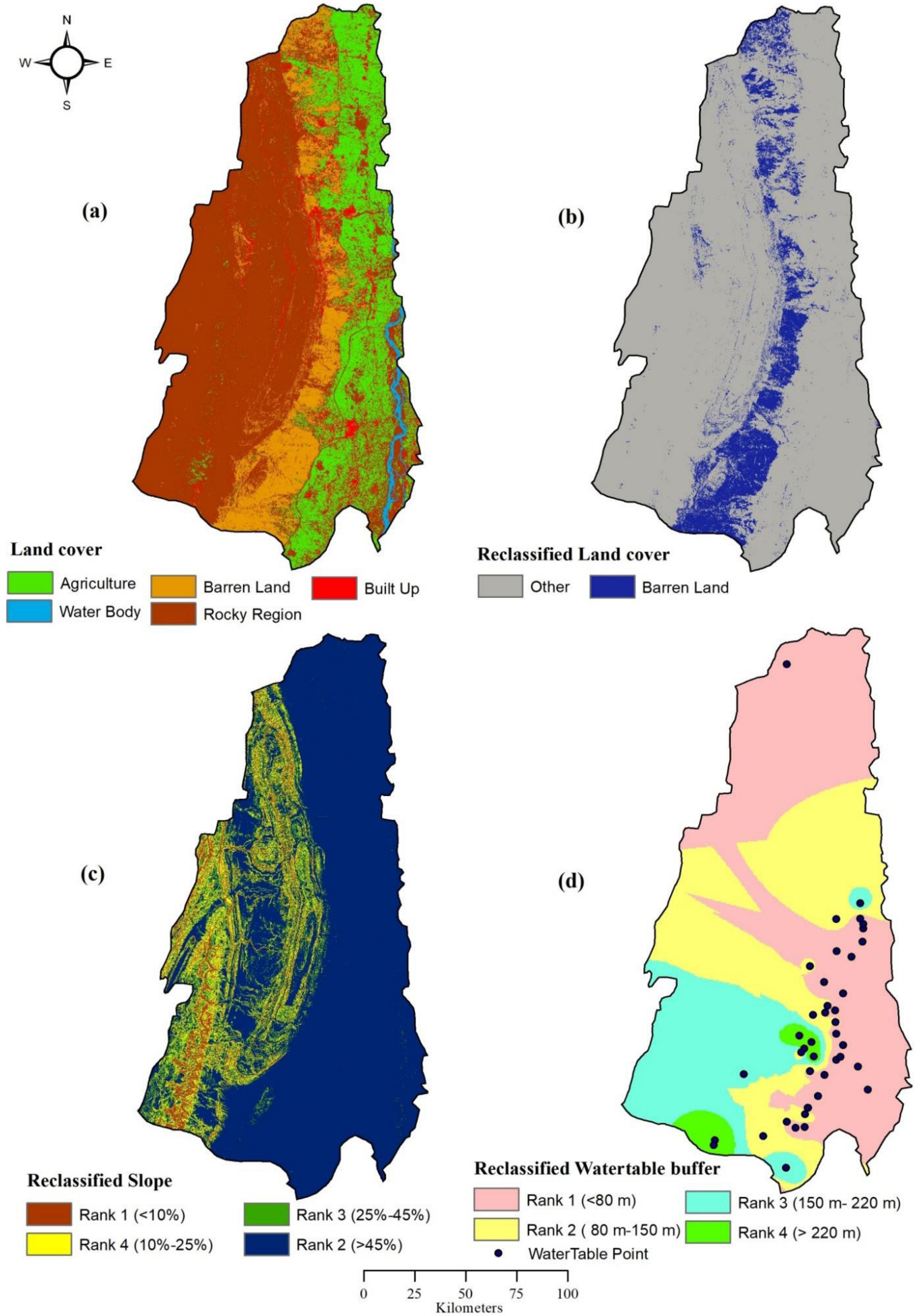

Figure 4. (a) Land cover map of the entire study area (b) reclassified raster map for land cover (c) reclassified raster map for slope (%) based on AHP ranking (d) reclassified interpolated raster map for water-table

3.2. Description for final suitable site for disposal waste:

To select the appropriate waste disposal site for this study area, various locations are compared according to their ecological, social, economic, and environmental effects. The comparative significance of each factor is determined by calculating weights for all land use/ land cover, slope, railway, river and streams network, roads, settlements, and water table maps as shown in figure 5. Outside the study area, approximately 0.84% (99 km) of the land falls into the "highly suitable" category, while the "moderately suitable" category accounts for 26.16% (3,071 km). The "least suitable" category covers 70% (8,218 km) of the area, and the "completely unsuitable" category represents 3% (350 km) of the total D.G. Khan District area as shown in figure 6.

4. Discussion

Approximately all main cities in Pakistan currently lack proper facilities for safe disposal practices and effective planning by municipalities. Solid waste is commonly dumped in available ravines or depressions along roads (Nisar et al., 2008). This mismanagement leads to two major problems: the spread of transmissible diseases and an unhealthy environment. Augmenting growth rate and waste production, coupled with ineffective administration, and malfunctioning municipal systems, contribute to these complications (Nisar et al., 2008). Several other reasons also lead to the failure of municipal waste management, including unplanned urban integration, lack of public awareness, inadequate resources, and insufficient equipment and funds.

The analysis indicates that suitable locations for waste disposal site construction in D.G. Khan District are limited. The government must take the initiative to reduce waste through reuse and recycling activities. Since the selection procedure for landfills must be holistic, more research should be carried out in the final decision-making phase including more high resolution and detailed datasets. Additionally, other important socioeconomic factors such as social, monetary, and economic parameters should also be considered when making the final decision.

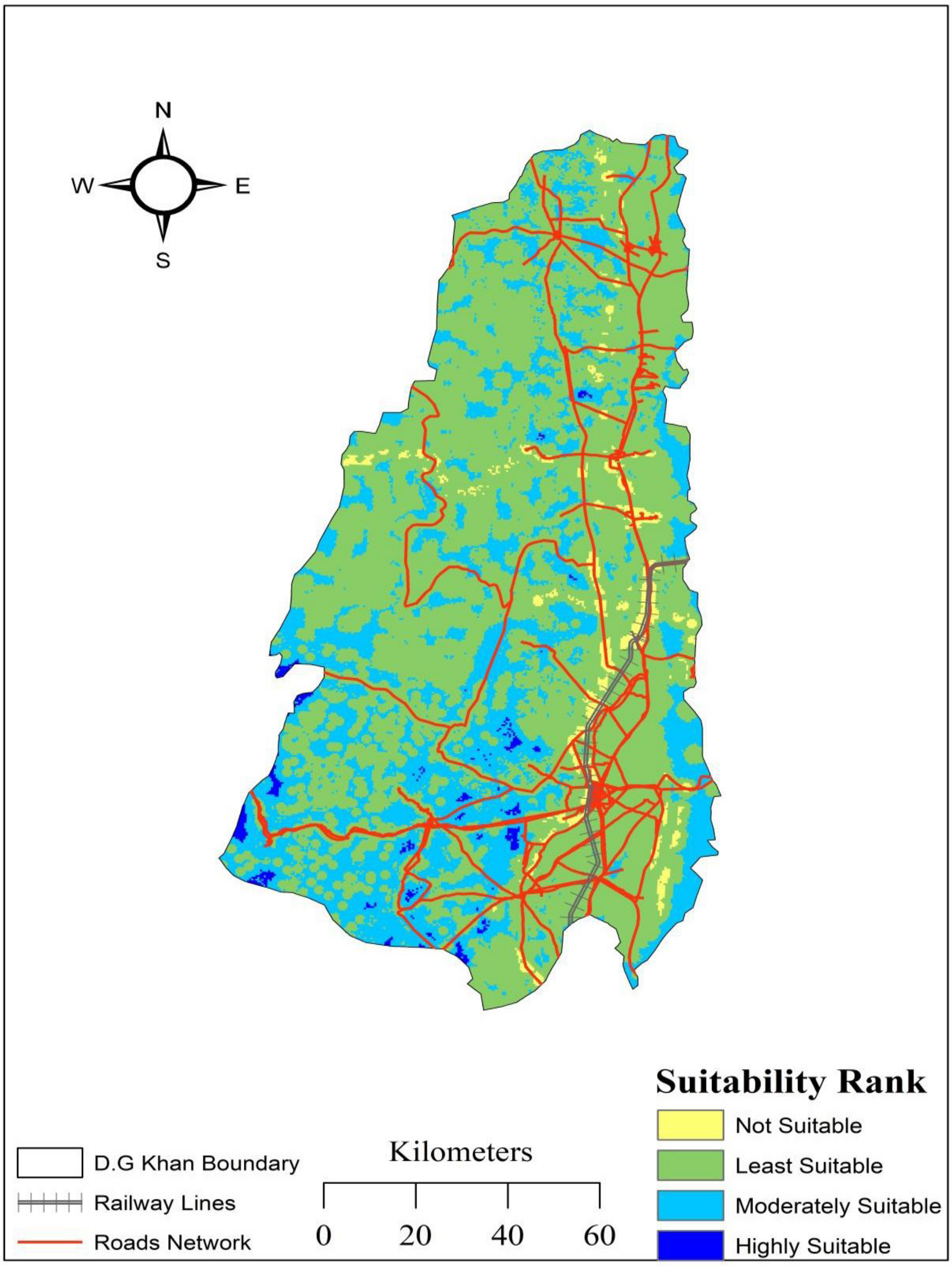

Figure 5. Overall Suitability Map for Selection of Landfill Site

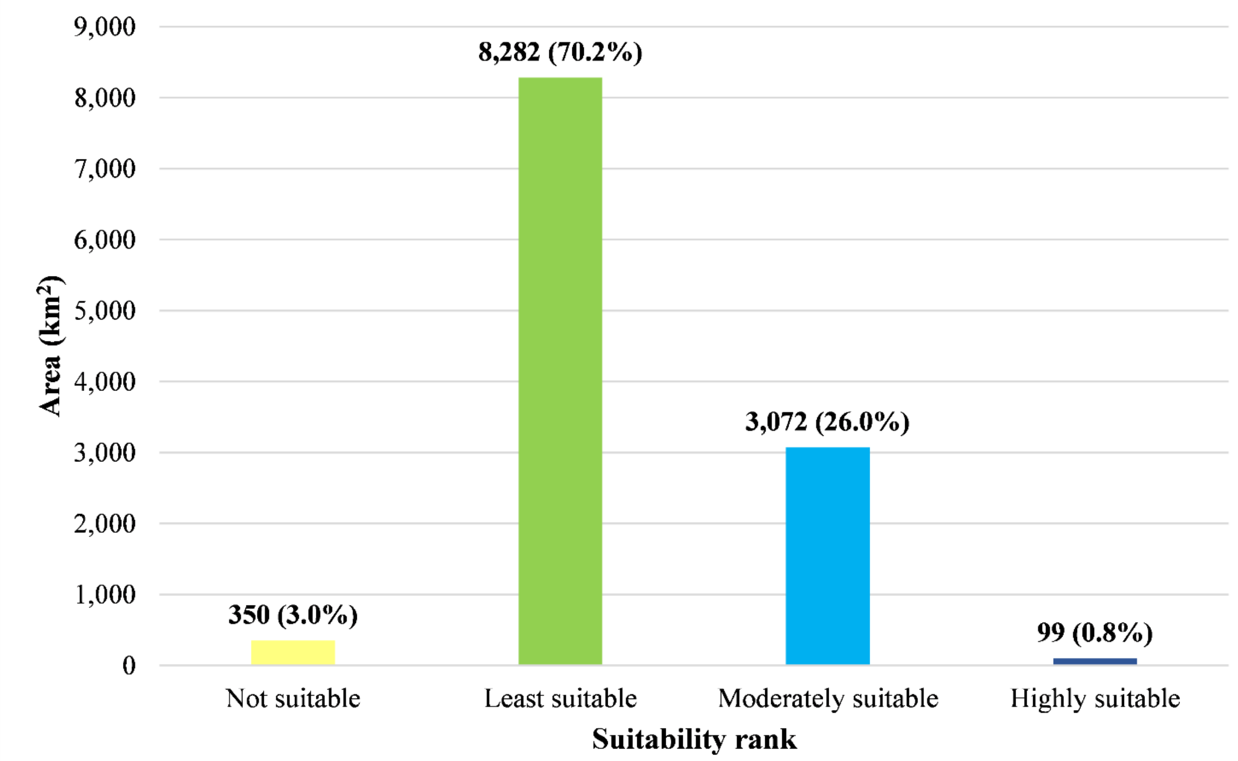

Figure 6. Graph depicting area-wise suitability ranks for waste disposal sites in the study area

A well-designed waste disposal site should achieve essential goals, preventing contamination of soil, underground, and surface water. Besides, all filling points should be far from densely populated areas to reduce its pollution effects on health (Kumar et al., 2015). Contrastingly, waste disposal sites should not be too far from existing roads to reduce transportation costs. Seven eligibility criteria are used in this study to find appropriate disposal sites. Maps are generated for every available criterion and final composite map is made by simply overlaying these individual maps using weights through AHP. Distance zones are established for creating buffer and assigning ranks, which are shown in Table 2. The weights are evaluated to account for potential variations in natural site conditions, and appropriate technical interventions are considered to enhance their suitability.

This study highlights the simplification of complex queries, such as locating hazardous waste disposal sites, through the use of MCA and GIS techniques. Nascimento et al. (2017) applied these methods to examine research in California, USA, to determine the optimal location for constructing a waste landfill in an urbanized district. GIS not only serves as a substitute for fieldwork but also saves time (Mohammed et al., 2018). However, before planning or creating a technical project, a comprehensive geotechnical survey should be carried out before determining the waste disposal site's location. This practice heavily relies on expert skills and knowledge about local conditions, making it an essential requirement. This work is based on several key criteria depending on the overlap analysis, resulting in four main categories: highly suitable (0.84%), moderately suitable (26.16%), less suitable (70%), and completely unsuitable (3%) regions.

Land resources for landfilling have become increasingly unfeasible as cities have experienced economic and environmental growth (Yasin et al., 2017). According to Integrated Solid Waste Management report, the population of D.G. Khan District was 397,114 in 2018. Using the arithmetic growth method, the projected population for the subsequent five years (2023) is estimated to be 477,114, and it is expected to further increase to 573,295 and 688,826 in the years 2028 and 2033, respectively. According to current estimated demographics and national per capita solid waste standards, D.G. Khan produced approximately 168.59 tons/day of municipal waste in 2018. With rough estimates that Pakistan's current population generates between 0.283 and 0.612 kg/capita of solid waste per day (http://epd.punjab.gov.pk/?q=solid_waste), the current per capita waste generation in D.G. Khan is 0.4 kg, and it is expected to increase by 1.5% annually.

Due to population growth and increasing economic activities, D.G. Khan's daily waste generation is projected to accelerate to 0.457 kg/capita/day and a total of 218.22 tons/day in 2023. This number is expected to rise even faster, reaching 0.531 kg/capita/day and a total of 365.62 tons/day by 2033. This massive increase in municipal waste production could lead to disastrous consequences in future if a plan is not devised and implemented. Therefore, it is highly recommended to promote the establishment of recycling facilities to manage this colossal amount of waste effectively.

While this research has been carefully designed, there are certain limitations. Other factors, such as lithology and permeability, can also impact site selection for landfills, but they are not considered in this study due to unavailability of the data. Future research in other regions should be conducted to explore these additional factors and their influence on landfill site selection.

5. Conclusion

This study focused on the complications associated with waste disposal site identification in D.G. Khan and their possible implications on residential communities. As there are no existing landfill sites in D.G. Khan District, this research aimed to select an appropriate waste disposal site using GIS-based multi-criteria analysis. By utilizing GIS, unsuitable areas could be disregarded, allowing for more comprehensive, detailed, and cost-effective studies of the remaining regions. GIS with its various functions, facilitated cost reduction and faster achievement of the research goal. The analysis process incorporated seven layers of criteria into GIS, namely settlements, rivers and streams, road network, water table, land use and land cover, slope, and railway, each layer considered for its significance in the overall assessment of suitable landfill sites.

The AHP technique is applied to determine the criterion weights through pair-wise comparison by creating a comparison matrix. The weighted linear combination method is then applied to all criteria to create the final output map, representing the suitability index of the district for landfill purposes. The results indicate that the most suitable locations for waste disposal sites are situated in the southwestern part of the study area. These locations are easily accessible and can effectively manage solid waste disposal while being at a safe distance from water bodies and other analyzed variables. The final output identified highly suitable areas covering 0.84% of the total area, moderately appropriate regions covering 26.16% area, least suitable regions covering 70% area, and areas considered unsuitable for landfill purposes covering 3% of the total area of D.G. Khan District.

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