DOI: 10.35595/2414-9179-2025-1-31-574-598

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GIS-BASED MULTI-CRITERIA EVALUATION FOR LANDFILL SITE SELECTION IN KOKAND CITY AND ADJACENT DISTRICTS

ABSTRACT

The study presents a comprehensive GIS-based Multi-Criteria Evaluation (MCE) approach for identifying optimal landfill sites in Kokand City and its adjacent districts, Uzbekistan. Rapid urbanization and population growth have exacerbated waste management challenges in the region, necessitating scientifically sound solutions for sustainable landfill placement. The research integrates geospatial analysis with the Analytical Hierarchy Process (AHP) to assess environmental, economic, and social constraints, ensuring minimal ecological impact while maximizing operational efficiency. Eight key criteria were evaluated: distance from roads (300 m buffer), railways (300 m), water bodies (500 m), settlements (500 m), airports (5 km), agricultural lands (300 m), slope (<6°), and elevation (<500 m). Using ArcGIS 10.8, constraint maps were generated, revealing that 99.8 % of the study area is unsuitable due to regulatory restrictions. Only three sites (A — 95 ha, B — 38 ha, E — 62 ha) met all safety requirements. AHP-weighted rankings prioritized airport proximity (31.6 %) and settlement distance (17.2 %) as critical factors, while slope (5.9 %) and elevation (4.9 %) had lesser influence. The consistency ratio (CR = 0.03) validated the reliability of the pairwise comparisons. This study underscores the efficacy of GIS-MCE in landfill siting, offering a replicable framework for regions facing similar waste management crises. The authors recommend future research incorporating groundwater depth and soil permeability to further refine site suitability. The findings provide actionable insights for policymakers, promoting environmentally responsible urban planning in line with Sustainable Development Goals (SDGs).

KEYWORDS: landfill location, multi-criteria evaluation (MCE), analytical hierarchy process (AHP), Kokand City, environmental management

INTRODUCTION

The city of Kokand and its surrounding districts, located in the western part of the Fergana Region, have been characterized by constant population growth since independence [*Temirov*, 2022]. Population growth has created several problems in the sustainable urbanization process [*Senzige* et al., 2014; *Rukundo*, *Ariho*, 2022]. One of these problems is the increase in solid household waste, an urgent issue that must be addressed in environmental protection and urban planning. Of the 7–9 million tons of waste generated annually in the Republic, 22 % falls into the Fergana Region. Approximately half of the waste generated in the region falls into the city of Kokand and the surrounding areas [*Rakhmatullayev* et al., 2020].

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This study aimed to identify alternative areas for the location of a new landfill serving the city of Kokand and its surrounding districts. A geographic information system (GIS) and multi-criteria evaluation (MCE) technologies were used to determine the landfill area. These methods simultaneously account for the environmental, economic, and social constraints at the same time [*Barakat* et al., 2017; *Singh*, 2019; *Rahimi* et al., 2020]. The criteria for landfill location include environmental safety, economic efficiency, and social impacts. Some of these factors are complex and conflicting, which makes landfill selection difficult [*Rahmat* et al., 2017].

This study was based on landfill location guidelines developed by the Ministry of Ecology, Environmental Protection, and Climate Change of the Republic of Uzbekistan and the Research Institute of Environmental and Nature Protection Technologies.

The main objectives of this study are based on two aspects. The first is the rapid growth of the population and the second is the unusability of existing landfills. In particular, the population of Kokand City has increased by 173 223 between 2013 and 2023, with an average growth rate of 16 % over 10 years. The current state of the existing landfill located in the Dangara District does not meet these requirements. The landfill is full and waste is dumped without sorting or recycling. If waste is not properly recycled or disposed of, it inevitably has a negative impact on the health of the population living in such areas [*Somani*, 2023].

Existing landfills cannot effectively manage the amount of waste generated and do not meet environmental safety requirements. Therefore, the location of new and alternative landfills is an important and urgent issue (Fig. 1).

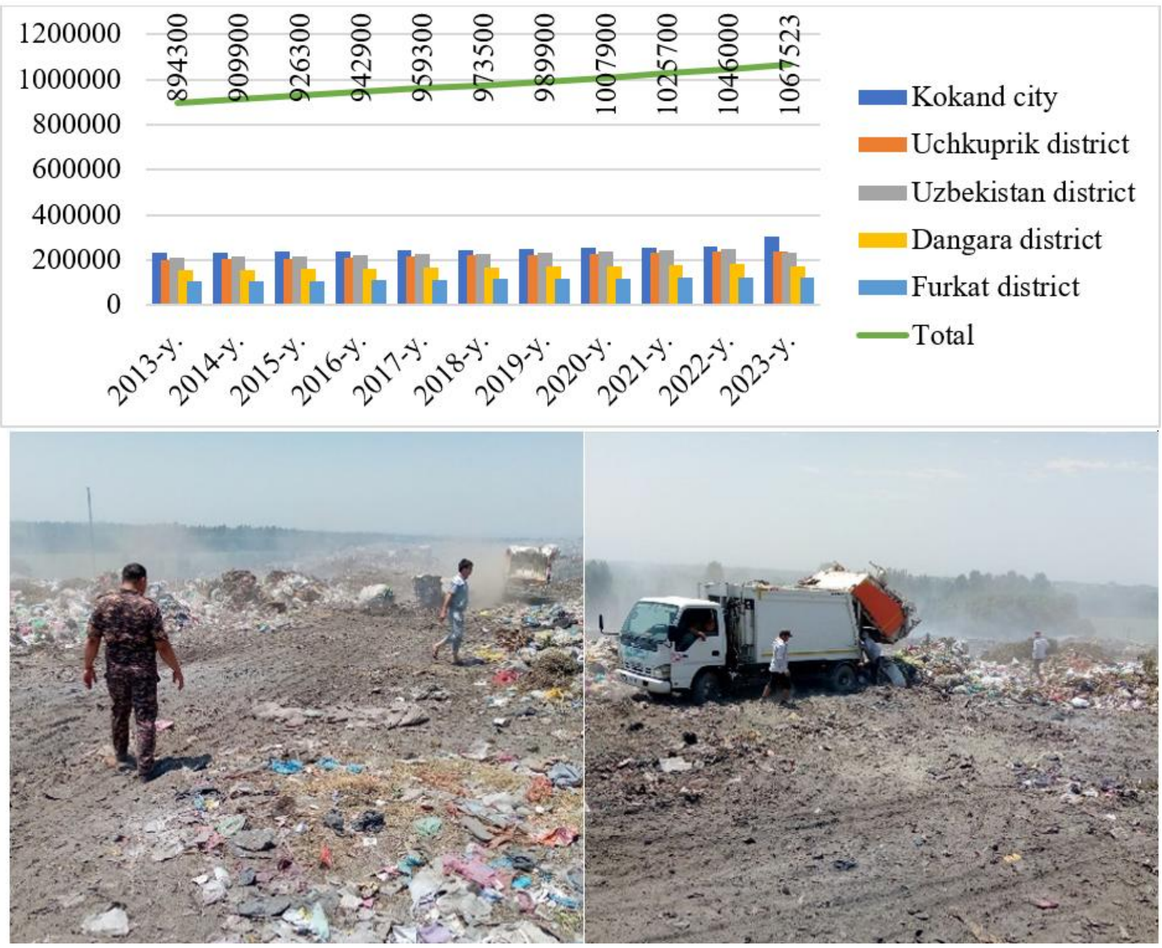

Fig. 1. Problem identification. Source: Compiled by the author based on data from the Fergana Regional Statistics Department

RESEARCH MATERIALS AND METHODS

Study area

The study area covers the city of Kokand, located in the eastern part of the Republic of Uzbekistan, in the western part of the Fergana Region, and four adjacent districts — Uchkuprik, Dangara, Furkat and Uzbekistan districts. The geographical coordinates of the area are from 40°18′ to 40°76′ north latitude and 70°59′ to 71°11′ east longitude (Fig. 2). The total study area was 1 736.3 km².

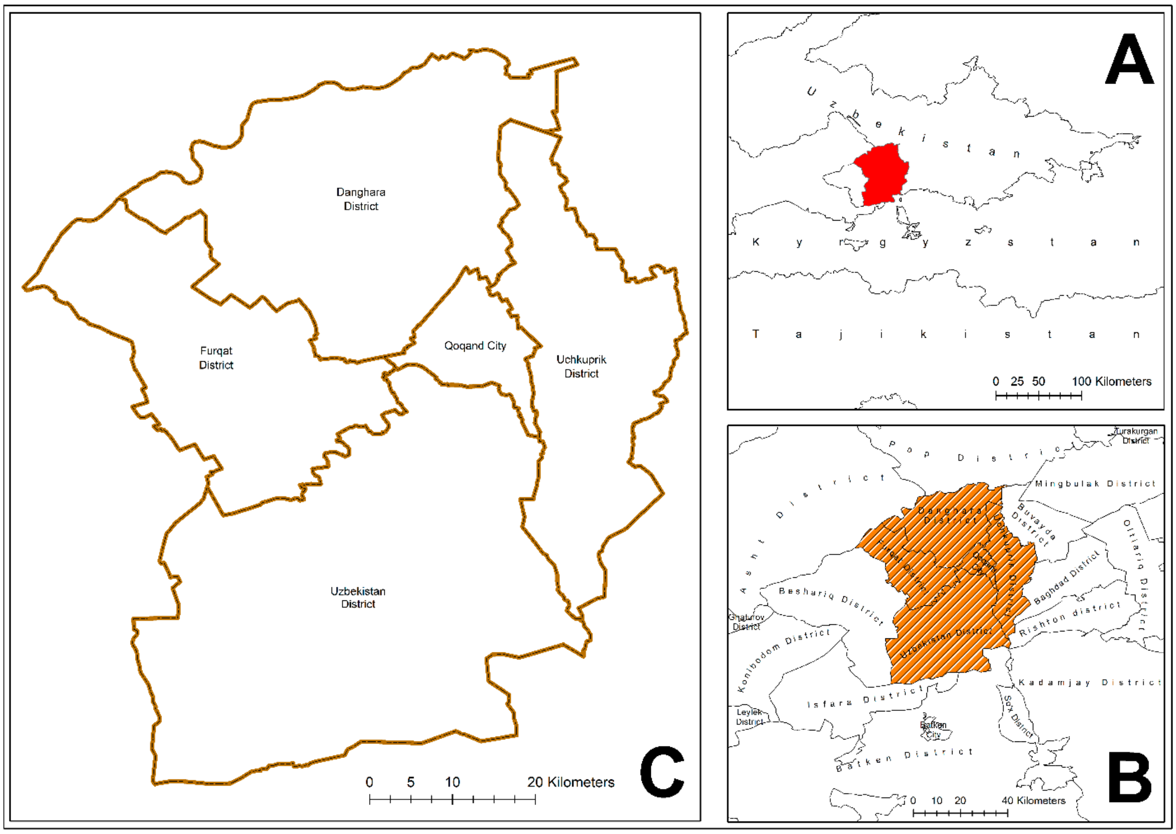

Fig. 2. Location of the study area. a) The location of the Fergana Region on the map of the Republic of Uzbekistan. b) The location of the study area on the administrative map of the Fergana Region. c) The border map of Kokand City and its neighboring districts (Dangara, Uzbekistan, Furqat, and Uchkuprik districts). Source: Compiled by the author

The city of Kokand and its surrounding districts, located in the western part of the Fergana Region, have been characterized by constant population growth since independence [*Temirov*, 2022]. Population growth has created several problems in the sustainable urbanization process [*Senzige* et al., 2014; *Rukundo*, *Ariho*, 2022]. One of these problems is the increase in solid household waste, an urgent issue that must be addressed in environmental protection and urban planning. Of the 7–9 million tons of waste generated annually in the Republic, 22 % falls into the Fergana Region. Approximately half of the waste generated in the region falls into the city of Kokand and the surrounding areas [*Rakhmatullayev* et al., 2020].

The length of the area from north to south is 66.8 km, and from east to west is 43.8 km. The borders of the city of Kokand and its adjacent territories and their locations with neighboring districts are shown in. The territory is located at an average altitude of 346–1 300 meters above sea level, and this difference in relief affects the natural and socioeconomic characteristics.

According to the 2023 Fergana Regional Department of Statistics, the total population in this territory is 1 067 523 people. In terms of population density and level of development, the territory is considered economically active. The study area mainly specializes in trade and services, light industry, manufacturing, and agriculture.

Administratively and territorially, this territory includes two cities, 51 towns and 395 villages. This territory is considered to be one of the growing centers of economic and infrastructure development and is important for the study of natural and anthropogenic processes.

In urban areas, the average amount of solid domestic waste per capita per day ranges from 0.7 kg to 0.8 kg. According to SanPiN RUz No. 0297-11, the average standard for the accumulation of solid domestic waste for one person in populated areas is set at 1.17 kg per day (437.7 kg per year).

In rural areas, the average amount of waste per capita per day is 0.5 kg. Because a large portion of organic waste (food scraps, plant stalks) in rural areas is reused as feed for livestock or as compost, the total amount of waste disposed of in landfills is lower (Table 1).

Table 1. Municipal waste indicators for the administrative units of the Fergana Region

Administrative	**Polygon area (ha)**	**Number of polygons**	**Population (thousand)**	**Urban population (thousand)**	**Rural population (thousand)**	**Urban waste amount (thousand kg)**	**Rural waste amount (thousand kg)**	**Total daily (thousand kg)**	**Annual waste amount (thousand tons)**
Bagdod District	20.7	0	223.3	114.4	109	91.5	54.5	146	53.3
Beshariq District	9.8	1	234.6	82.4	152.2	65.9	76.1	142	51.8
Buvayda District	2.6	1	236.2	110.7	125.4	88.6	62.7	151.3	55.2
Dangara District	15.4	1	180.8	42.2	138.6	33.8	69.3	103.1	37.6
Fergana City	0	2	299.2	299.2	0	239.4	0	239.4	87.4
Fergana District	80.4	2	220.9	138.5	82.5	110.8	41.25	152.1	55.5
Furqat District	0	0	121.8	28.6	93.1	22.9	46.55	69.4	25.3
Margilan City	0	0	242.5	242.5	0	194	0	194	70.8
Oltiariq District	47.9	1	219.1	164.9	54.1	131.9	27.05	159	58
O’zbekiston District	0	0	246.4	106.6	139.8	85.3	69.9	155.2	56.6
Kokand City	0	0	259.7	259.7	0	207.8	0	207.8	75.8
Koshtepa District	0	0	198.4	76.5	121.9	61.2	60.95	122.2	44.6
Kuva District	4.6	1	266	123.2	142.8	98.6	71.4	170	62
Kuvasoy City	28.8	1	96.9	54.4	42.4	43.5	21.2	64.7	23.6
Rishton District	1.1	1	208.4	132.9	75.4	106.3	37.7	144	52.6
Sokh District	5.5	1	80.6	51.1	29.6	40.9	14.8	55.7	20.3
Toshloq District	0	0	209.7	48.5	161.3	38.8	80.65	119.5	43.6
Uchkoprik District	18.1	1	237.3	43.2	194.1	34.6	97.05	131.6	48
Yozyovon District	0	0	114.7	69	45.7	55.2	22.85	78.1	28.5
Total	235	13	3 896.5	2 188.5	1 707.9	1 750.8	853.95	2 604.8	950.7

Source: Compiled by the author

Method

The selection of a polygon area requires the inclusion of several factors in the decision-making process, which complicate the process. Multi-criteria evaluation (MCE) technology based on a geographic information system (GIS) increases efficiency under such conditions because of its ability to manage large volumes of spatial data [*Dar* et al., 2019]. In this study, Esri ArcGIS 10.8 was used for analysis, and various tools of GIS software, including buffer, clip, intersect, union, merge, dissolve, identify, and weighted overlay, were widely used.

Data for this study were divided into two groups. Primary data were obtained from various organizations, including Sentinel-2 Land Cover Explorer, OpenStreetMap open data platform, and Fergana Regional Statistics Department. Secondary data were processed and generated from primary sources as a result of the cartographic operations. This study was conducted in three stages.

Delimitation of the restricted area and identification of alternative locations

This study evaluated the following criteria for delimiting suitable and restricted landfill areas: roads, railway lines, airports, water bodies, agricultural land, residential areas, slopes, and heights. The buffer distances for each criterion were based on instructions provided by the State Committee for Ecology and Environmental Protection of the Republic of Uzbekistan (Table 2). Buffer distances mitigate potential exposure and land-use conflicts for nearby receptors by enforcing minimum setbacks from sensitive features.

Table 2. Buffer distance used for different factors

No.	Features	Buffer distance (meters)
1	Road networks	300
2	Railway lines	300
3	Water bodies	500
4	Built-up area (populated areas)	500
5	Airport	5 000
6	Agricultural land	300

Constraint maps were created using the "Layers" function in GIS software, and these maps supported various scenarios for analysis. The minimum suitable area for landfill placement was 30 ha. As a result of the analysis, three alternative locations were selected: A, B, and E. Agricultural buffers in these areas were not considered because these areas can be selected from agricultural lands for landfills from the perspective of sustainable development in densely populated cities and districts.

AHP and MCE techniques to determine the suitability of the location

Eight main criteria were considered in the evaluation of alternative locations: distance from road networks, railway lines, airports, water bodies, agricultural lands, residential areas, slope, and altitude. The importance of each criterion was assessed using an Analytical Hierarchy Process (AHP)[1]. A pairwise comparison matrix was constructed based on the Saaty scale and the weights were calculated (Table 3).

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[1] Web resource: https://bpmsg.com/tag/ahp-weight-calculation/ (accessed 06.06.2025)

Table 3. Saaty scale for the AHP process

Intensity of importance	Description
1	Equal importance
2	Weak or slight importance
3	Moderate importance
4	Moderate plus importance
5	Strong importance
6	Strong plus importance
7	Very strong importance
8	Very, very strong importance
9	Extreme importance

The consistency coefficient (CR) of decisions is calculated using the AHP process. If the CR value is 0.1 or less, the matrix was considered consistent [*Khodaparast* et al., 2018]. The data were normalized to ensure data integrity.

The multi-criteria evaluation (MCE) technique allows the evaluation of alternative locations in the order of suitability [*Yildirim* et al., 2018]. In this process, the normalized data for each criterion were multiplied by weights and an overall indicator was calculated. The location with the highest suitability score was determined to be most suitable for the city of Kokand and its surrounding areas.

Multi-Criteria Evaluation (MCE)

Multi-criteria evaluation (MCE) technology is widely used in the decision-making process, and allows users to make the most optimal choice among many criteria [*Motlagh*, *Sayadi*, 2015; *Mohammed* et al., 2019; *Helal*, 2022; *Ampofo* et al., 2023]. The combination of GIS and MCE methods creates an effective environment for managing and analyzing complex geographic data [*Mvula* et al., 2023]. For issues related to site selection, GIS plays an important role in assessing the impact of indicators and delineating buffer zones [*Majid*, *Mir*, 2021].

The MCE method is especially effective in solving problems faced by decision makers when working with large amounts of complex data. The basic principle of this technique is to divide the decision-making process into small parts, evaluate each part separately, and then combine all the parts to form a final decision [*Muayad*, *Janna*, 2023]. The integration of GIS and MCE makes the decision-making process for selecting landfill locations more efficient. Although GIS facilitates data management and analysis, it also provides reliable rankings by considering multiple criteria [*Aarthi* et al., 2023].

The MCE also provides tools for coordinating conflicting criteria in decision-making. These tools also allow for complex trade-offs, considering the experience and knowledge of the decision maker.

Analytical Hierarchy Process (AHP)

The Analytical Hierarchy Process (AHP) was developed as a decision-making method by Thomas Saaty in 1980. A combination of GIS and AHP is a powerful tool for developing strategies for urban development and resource management [*Aburas* et al., 2016; *Tobirov* et al., 2024]. AHP aims to optimize complex decision-making processes and help decision-makers select the most appropriate decision.

The AHP simplifies the decision-making process by reducing the number of decisions to a sequence of pairwise comparisons [*Barakat* et al., 2017; *Macalam* et al., 2023]. The relative importance of each criterion was assessed on a numerical scale from one to nine, and the weight of each criterion was determined based on pairwise comparisons [*Dwivedi* et al., 2024]. The higher the weight, the more important is the criterion. AHP evaluates alternatives according to criteria and assigns them a score. A higher score indicates a preference for an alternative to the criterion [*Yadav*, *Prasad*, 2023; *Hosseinzadeh* et al., 2024].

In the AHP process, the results were combined with the influence of the scores for each criterion and a final rating was determined for each alternative. The final rating forms the final decision based on all the criteria. In addition, AHP was used to calculate the consistency ratio (CR) to check the logicality of the results and improve the decision-making process. The CR indicator is equal to the ratio of the consistency index (CI) to the random index (RI). If $CR < 0.1$, the decision-making process is considered to be consistent. If $CR \geq 0.1$, this indicates logical inconsistency in the results, and revision of the comparisons is required [*Saaty*, 1987].

The combination of GIS and MCE, including AHP, provides a scientifically sound approach for simplifying and optimizing complex decision-making processes.

Development of input data

Description of factors and derivation of constraint criteria

The identification of landfill sites in Kokand City and its adjacent districts is important because many factors are involved. This section includes the creation of thematic maps of the selected factors and corresponding buffers used for the constraint criteria.

Roads

Roads are an important component of transport systems in the study area. They connect the city of Kokand and adjacent districts and serve as the main means of transport for the population and economic activity. Roads are important for ensuring intercity and intra-district movement. Therefore, ensuring integration with the road infrastructure when locating landfills is both environmentally and economically important [*Dwivedi* et al., 2024].

The road network in this region increases the efficiency of existing transport systems. A digitized road map is presented in Fig. 3a, which shows the main road networks of the region. The length of the public road is 3 905 km. It is important to ensure convenient and cost-effective transportation from road networks to areas where landfills are located.

The geographical location of the roads in the region and the main indicators obtained were obtained from the OpenStreetMap open data platform. Based on this data, the optimal distances and safety zones were determined when planning landfills with road infrastructure.

The landfill should be located at an optimal distance from roads. Proximity to roads reduces the cost of transporting waste to landfills, minimizes the need for new road construction, and ensures the stability of transport infrastructure. Simultaneously, a safety buffer zone of 300 m was allocated on both sides of the road centerline to prevent negative impacts, such as litter and odors (Fig. 3b).

The following factors are considered when locating landfills in relation to roads: reducing transportation costs, that is, locating the landfill close to the road network, which reduces fuel and time consumption in transporting waste, and maintaining ecological balance, that is, locating it at a minimum distance from roads, which reduces pollution and negative environmental impacts along the road. It is important that landfills not cause inconvenience or danger to traffic when located near roads.

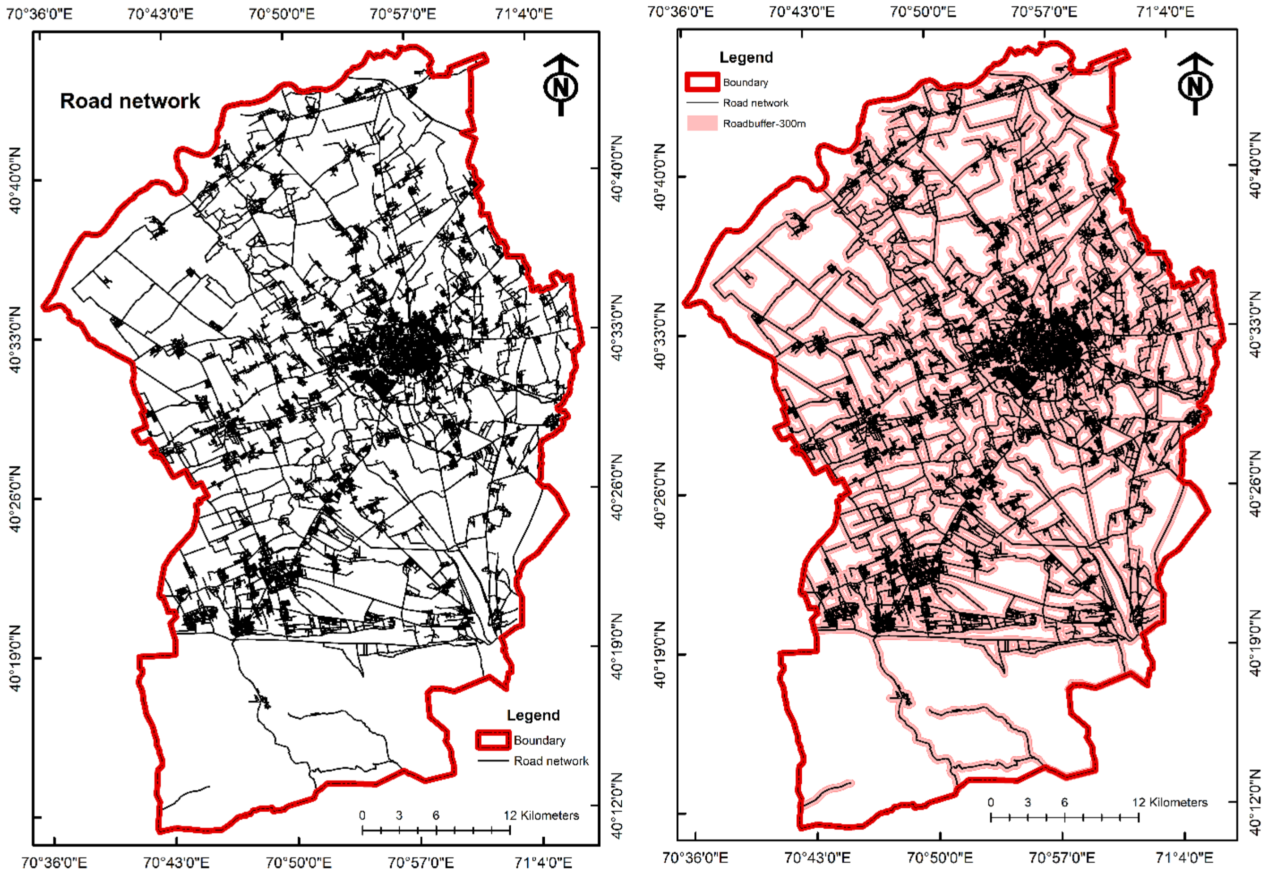

Fig. 3. Road network (a) and associated buffer (b). Source: Compiled by the author

When locating landfills, mutual integration with highways increases the stability of the transport system and efficiency of waste management. Simultaneously, it is necessary to establish a safety buffer to ensure environmental safety and to avoid harm to public health. This approach serves the sustainable development of the territory and effective management of resources.

Railway line

The railways in Uzbekistan are important freight and passenger transportation networks. Railway lines passing through the valley are not only of economic importance but also constitute the main part of the regional infrastructure. Railway lines passing through the study area play an important role in connecting populated areas with economic centers [*Yadav*, *Prasad*, 2023]. The total length of the railway network in the city of Kokand and adjacent areas was 142 km. This network is of great importance to the transportation and logistics sectors in the study area.

Information on railway lines was obtained from the OpenStreetMap open data platform. These data were analyzed during the study and used for territorial planning and landfill location. Maintaining the distance between the railway lines and landfills is necessary to ensure environmental and traffic safety. A 300-meter safety buffer zone was allocated along the railway lines (Fig. 4a, 4b). This buffer zone minimizes the environmental risks associated with transport infrastructure and landfills.

Priority is given to locating landfills at a distance from railway lines, as this helps reduce the following risks: the possibility of a negative impact on the movement of goods and passengers by rail, the spread of waste along the railway, environmental pollution, and increased fire risk in the transport system.

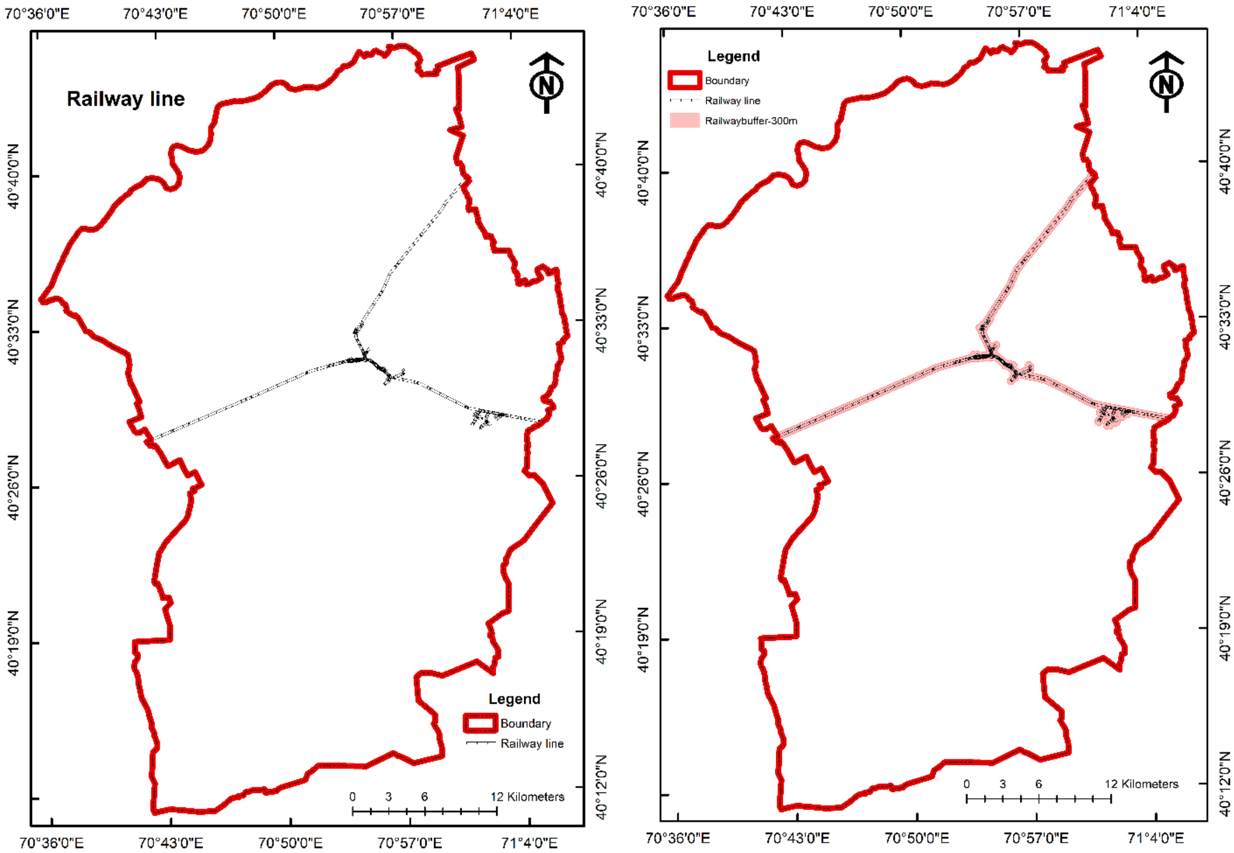

Fig. 4. (a) Railway line and associated buffer (b). Source: Compiled by the author

Locating landfills at a safe distance from railway lines provides stable operation of the transport infrastructure, ensuring environmental safety and socioeconomic development of the region. Therefore, the 300-meter buffer zone allocated around the railway plays an important role in the regional planning process.

Water bodies

When locating landfills, it is necessary to pay attention to the environmental and ecological safety of the surface water bodies. When landfills are located near water bodies, there is a risk of chemical or biological pollution of water through wastewater. To prevent this risk, it is important to maintain a safe distance from the water bodies [*Elkhrachy* et al., 2023].

There are two large rivers in the city of Kokand and adjacent areas: the Syrdarya and Sokh rivers, which are the main watercourses in the region. In addition, several canals and streams flowed through this area. The water resource system of the region also includes the Shorsuv Reservoir, which occupies a total area of 0.6 km². The total length of the existing waterways was 612 km.

To ensure environmental safety, a 500-meter safety buffer zone was established around the water bodies (Fig. 5a, 5b). This buffer zone is recommended for locating landfills at a greater distance from water bodies. This is an important factor in preventing chemical pollution in surface waters, maintaining the ecological balance of water, and protecting the health of populations using water resources.

Information on the water bodies in this region and their geographical locations was obtained using OpenStreetMap. Based on the analysis of the obtained data, it is possible to strengthen territorial security measures and identify suitable areas for landfill placement.

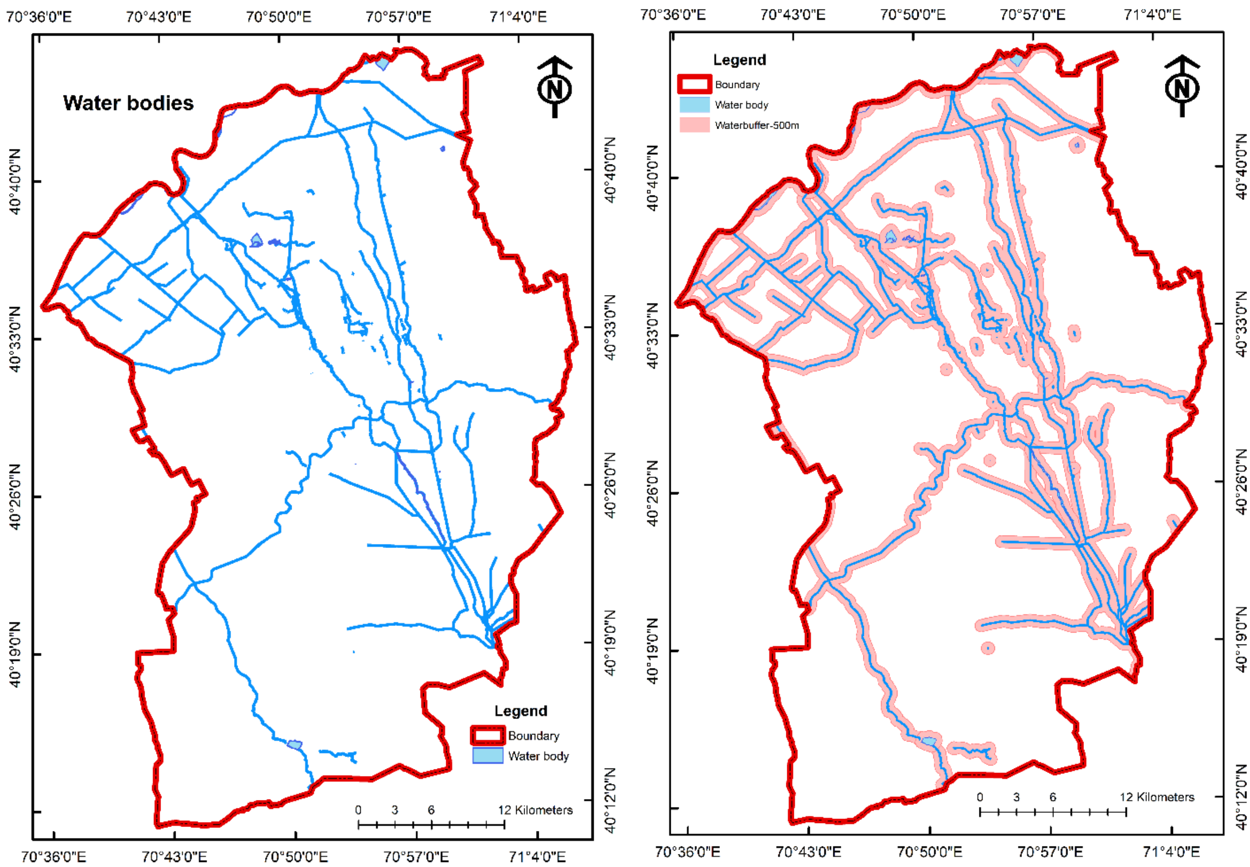

Fig. 5. Water bodies (a) and associated buffers (b). Source: Compiled by the author

Thus, considerable attention has been paid to the placement of landfills near water bodies, and measures have been taken to minimize environmental risks. This approach not only ensures the ecological stability of the region but also ensures the long-term protection of water resources.

Built-up area (population settlements)

Built-up areas, such as population settlements, include residential buildings, social facilities, parks, industrial complexes, and various other infrastructure. Proximity of these areas to landfills can lead to environmental and health problems. Landfills usually create favorable habitats for disease-carrying organisms such as rodents, insects, mosquitoes, and flies. Consequently, the location of such facilities near residential areas can increase air pollution, noise pollution, fire hazards, and epidemiological risk [*Manguri*, *Hamza*, 2022].

Therefore, it is important to ensure an ecologically safe and sanitary distance between residential areas and landfills when locating landfills. Open data from the Sentinel-2 Land Cover Explorer platform were processed and a map of population settlements was developed. For example, in the case of Kokand City and adjacent areas, a 500-meter safety buffer zone was allocated around residential areas (Fig. 6a, 6b). The total built-up area was 405 km². This buffer zone was established to protect the environment and public health. In addition, priority is given to locating landfills far from residential areas, which is important for ensuring the ecological safety of the area.

Airport

The proximity of airports should also be considered when locating landfills. The vicinity of airports is important to ensure air safety, maintain ecological balance, and reduce negative impacts on the environment. The impact of the Kokand Airport, its safety zone, and the landfill in the study area are analyzed below.

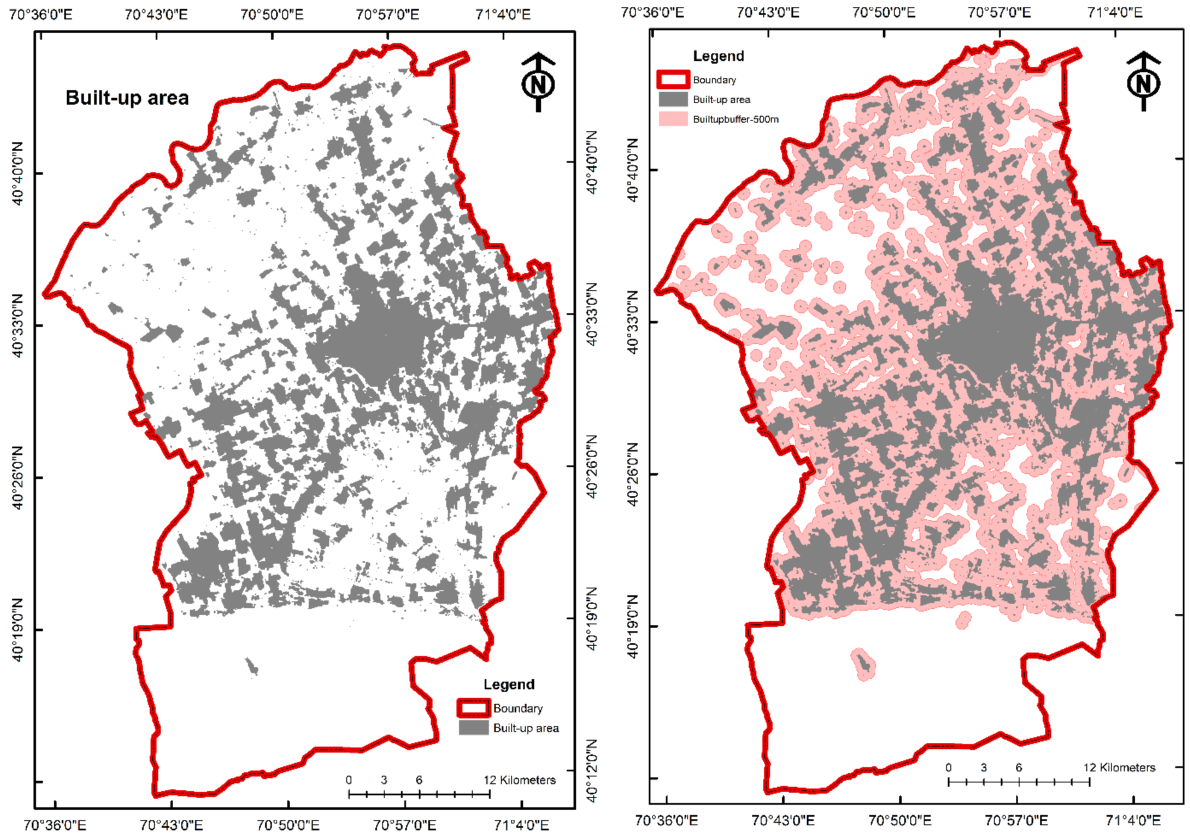

Fig. 6. Built-up area (a) and the associated buffer (b). Source: Compiled by the author

Landfills located near airports attract birds, because waste is a source of food for birds, particularly predators looking for meat and food. These birds gather near airports, increasing the risk of collisions with aircraft. According to the European Union Aviation Safety Agency, for the third quarter of 2021, the number of bird strikes was up more than 18 % from the same quarter in 2019, at 240.8 strikes per million flights[1]. These collisions usually damage aircrafts and, in some cases, end with human casualties. Therefore, locating landfills away from airports is key to reducing the risk to birds.

Kokand Airport is located in the eastern part of the study area in the Uzbek District, as shown in Fig. 7a. The total area of the airport is 164.5 ha, which emphasizes its importance for the transport infrastructure of the region. Considering safety and environmental requirements, a 5-km safety buffer zone was developed around the airport (Fig. 7b).

The buffer zone limits the approach of birds to aircrafts by increasing the distance between landfills and airports. A high weight was assigned to the location of the landfills in areas farther from the airport. When choosing an area, it is important to ensure environmental safety, while maintaining proximity to transport.

The map of the area and information about Kokand Airport were obtained from the OpenStreetMap open-data platform. Based on the geographic data obtained from this platform, safety zones were defined and cartographic analysis was performed.

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1 Systems R. R. Airport Bird Control. Airport Bird Detection, Mitigation Technology. Web resource: https://www.robinradar.com/resources/airport-bird-control-guide (05.01.2025)

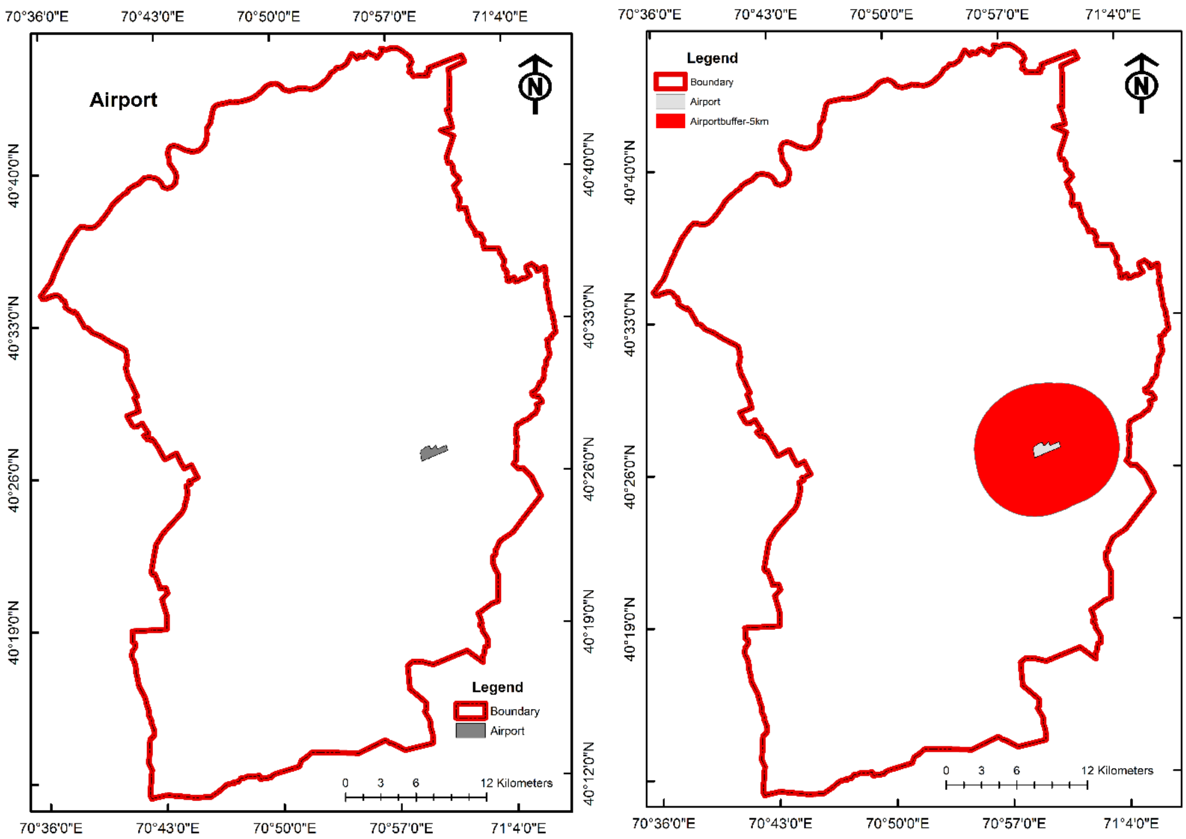

Fig. 7. Kokand Airport (a) and associated buffer (b). Source: Compiled by the author

It is important to consider safety zones when locating landfills near airports to reduce the risk of birds to aircrafts. The development of a 5-km safety buffer around Kokand Airport is aimed at protecting the ecology of the region and complying with the international aviation safety requirements. This approach not only protects the environment, but also creates a basis for the sustainable development of the region.

Agriculture

Environmental safety and soil quality preservation at landfill sites are important factors for the protection of agricultural areas. The study area is of great importance for agriculture and preserving the ecological state of these lands is particularly important when making decisions regarding landfill sites [*Chabuk* et al., 2017].

Wastewater that may be generated near landfills poses the risk of polluting agricultural fields. As a result of wastewater seeping into the ground and reaching the fields, soil fertility decreases and crops are damaged. Such effects can harm plants and affect the stability of the local ecosystems. Therefore, it is necessary to maintain a sufficient distance between landfills and agricultural areas.

Kokand and its adjacent districts have extensive agricultural areas. The area of agricultural land in the study area, delineated based on data from the Sentinel-2 Land Cover Explorer platform, was 902.5 km^2. The large size of this area plays an important role in the economic stability of the region. A 300-meter buffer zone was established to ensure a minimum distance between agricultural fields and landfills (Fig. 8a, 8b).

The identification and analysis of agricultural land were performed by processing data from the Sentinel-2 Land Cover Explorer open-data platform. This platform provides high-resolution spatial data for determining the land resources of the region. Based on these data, safety zones were defined around the agricultural lands. Fig. 9 provides a detailed overview of the locations of the agricultural lands and buffer zones.

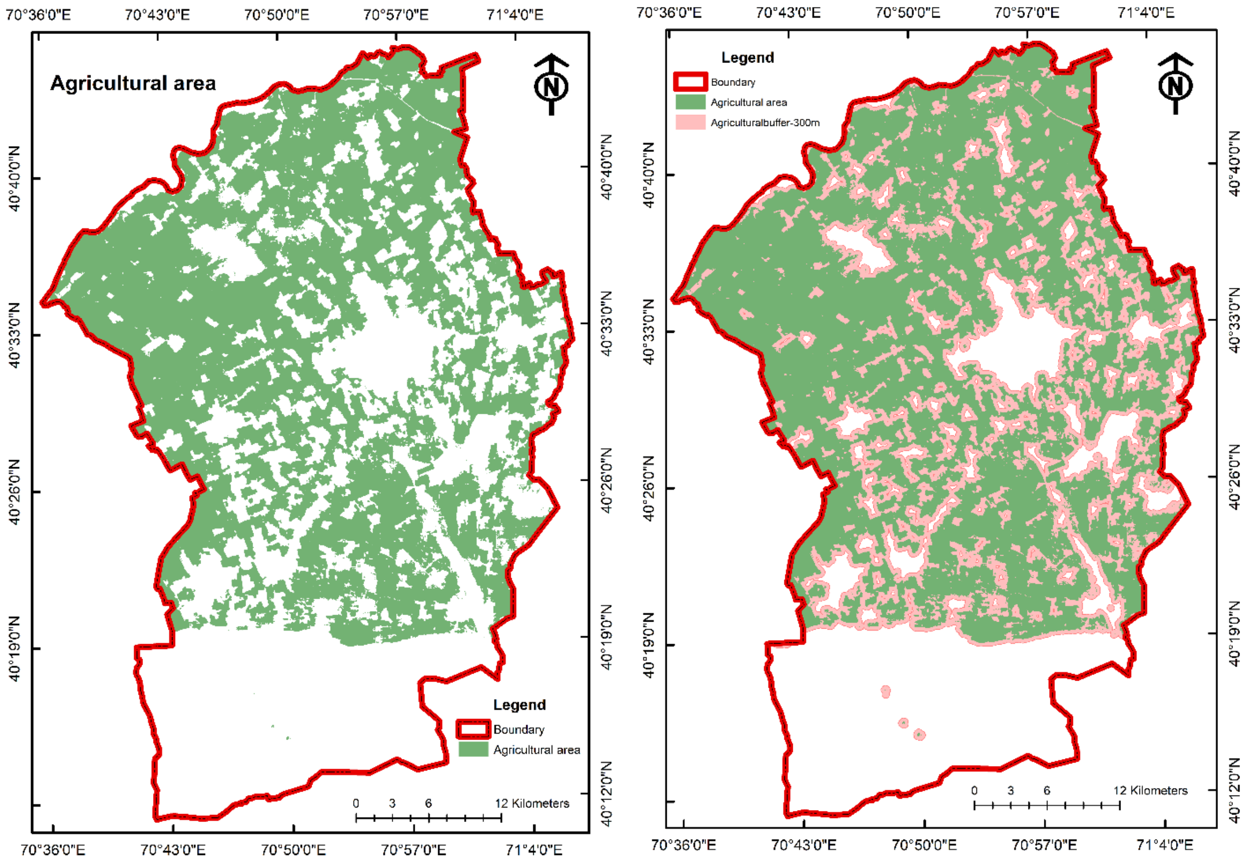

Fig. 8. Agricultural area (a) and the associated buffer (b).
Source: Compiled by the author

Slope

The slope of an area plays an important role in determining the topographic characteristics and locations of the landfills. Slope affects the speed of surface runoff, direction of flow, and ability of the soil to retain water and is a factor that must be considered when ensuring the environmental safety of landfill areas [*Rahmat* et al., 2017].

Steep slopes cause wastewater to move quickly and over long distances, thereby increasing the risk of pollution spreading over large areas. Steep slopes can increase erosion and damage soil fertility. Areas with relatively gentle slopes can retain water, ensuring that landfills do not harm the water resources. Therefore, it is advisable to locate landfills in areas with gentle slopes (i. e., less than 6°).

The slope map of the study area was created based on SRTM (Shuttle Radar Topography Mission) DEM (Digital Elevation Model) data, which allows for high-resolution mapping of the topographic features of the area. According to the slope map, the majority of Kokand City and its adjacent districts had slopes of less than 6°. Only the southern part is characterized by a slope of more than 6°, which is considered a less suitable area for landfill location (Fig. 9). The gentle slopes of the central and northern parts allowed us to identify these areas as more suitable for landfill locations.

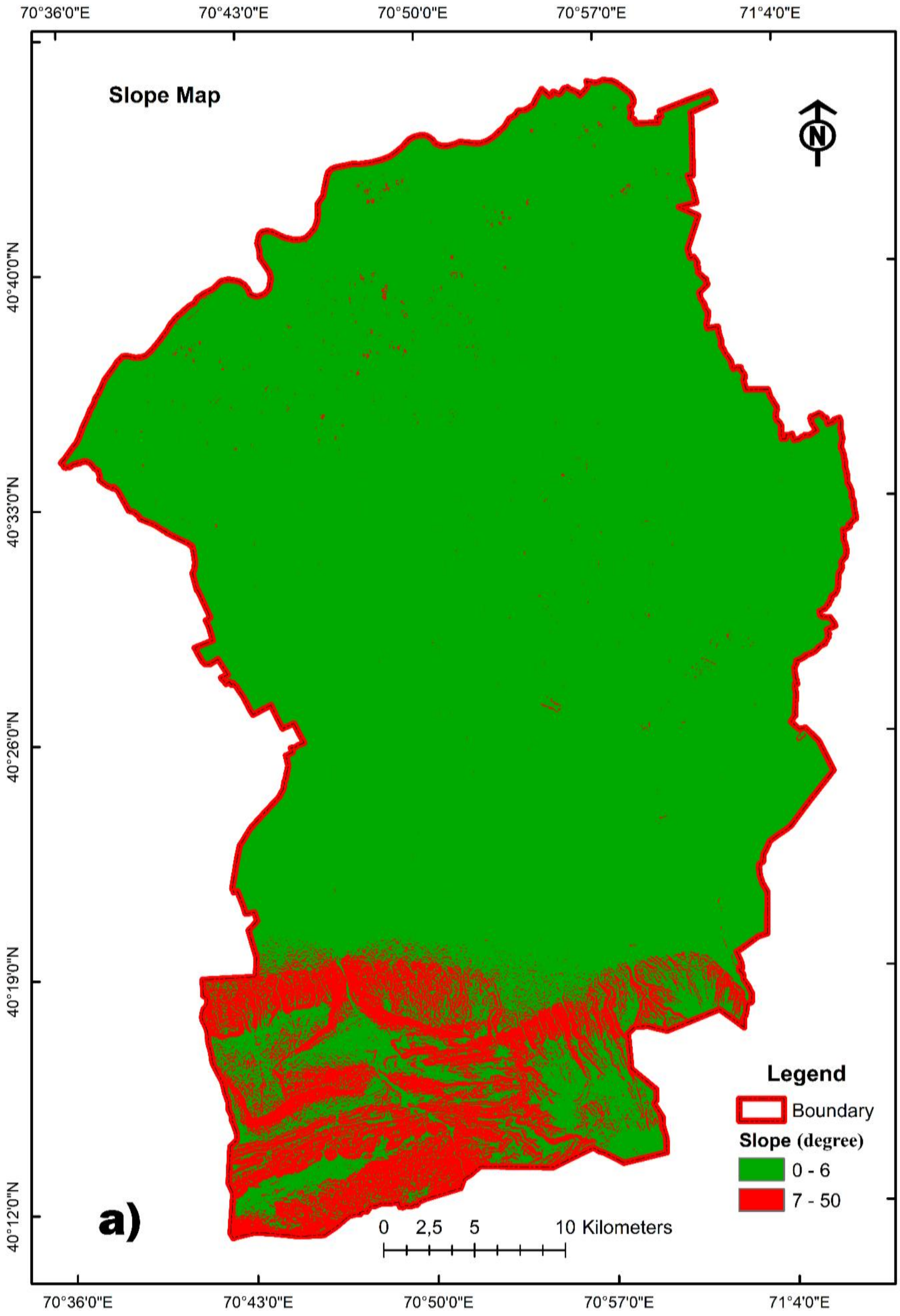

Fig. 9. Slope map. Source: Compiled by the author

Elevation

The elevation of an area is an important environmental and economic factor affecting landfill processes. Elevation changes play a significant role in determining transportation costs, ecosystem stability, and environmental impact [*Rahmat* et al., 2017].

The elevation determines the location of the landfill and the difficulty of accessing it. In areas located at high altitudes, increases in slope and elevation significantly increased transportation costs, particularly at high altitudes. This, in turn, increases the cost of operating and maintaining landfills. Areas at high altitudes are less suitable for landfills because they are difficult to access, which complicates the effective implementation of cargo operations.

An elevation map of the city of Kokand and adjacent districts was prepared based on the SRTM DEM data, which showed that the area was divided into different elevation zones. More than half of the study area is located at an altitude of less than 500 m. These areas are suitable for landfills because their transportation costs are lower and the environmental risk is lower. Altitudes of 501–800 m and 801–1 000 m are also suitable for landfills, but as you increase, transportation costs increase and environmental risks increase. Areas with altitudes above 1 000 m are the least suitable for landfills and are given lower weight owing to increased transportation costs and risks to ecosystems (Fig. 10).

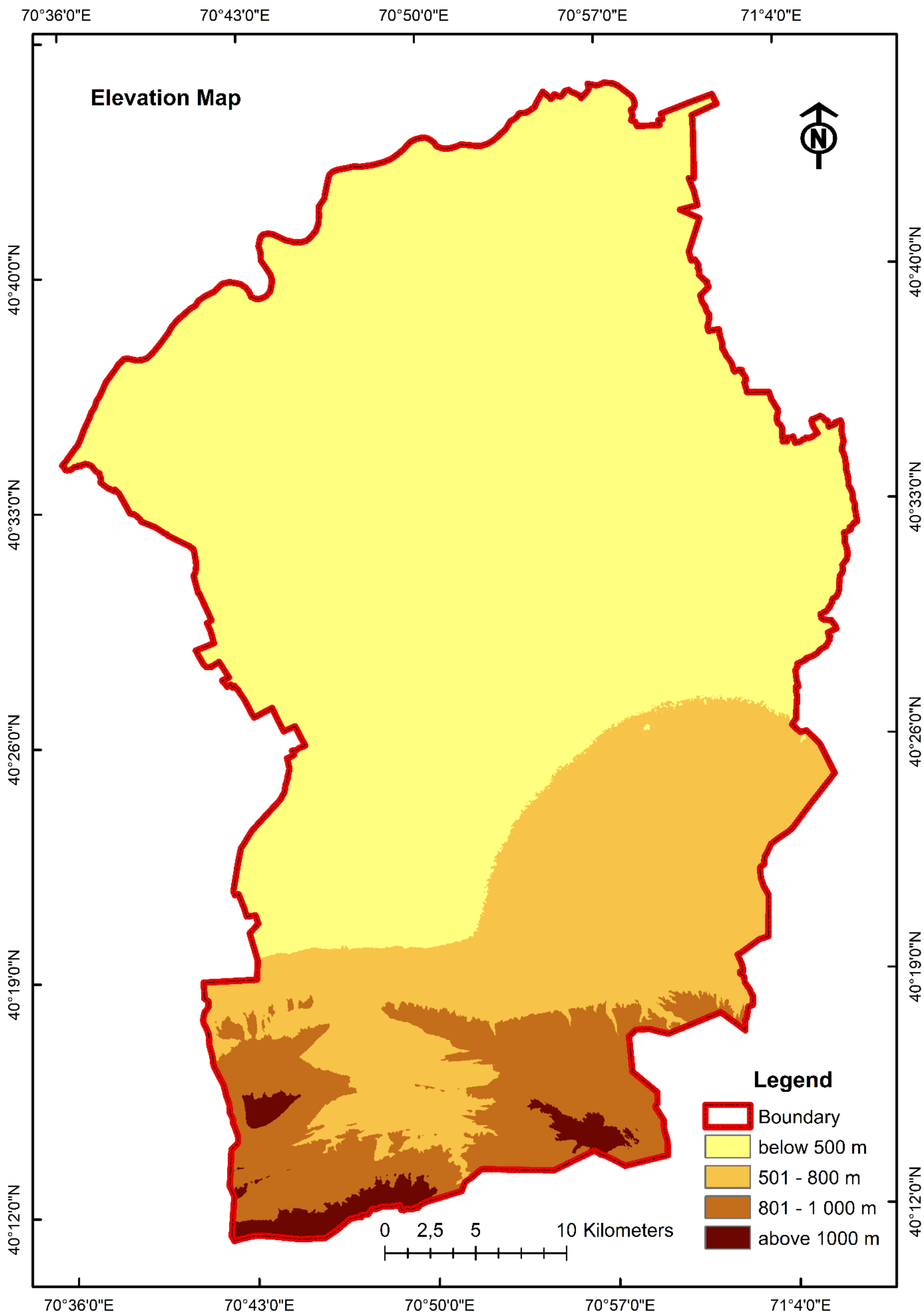

Fig. 10. Elevation map. Source: Compiled by the author

The lower elevations of the area, that is, below 500 m, are the most suitable for landfills, as they have lower transportation costs and environmental risks.

Size

The size of the landfill site requires consideration of several important factors when locating landfills. Among these factors, the population of the area, amount of waste generated, and the design life of the landfill are the most important. The size and location of a site determines the efficiency, environmental safety, and economic efficiency of the landfill.

The size of the landfill site depends primarily on the population of the area, the amount of waste generated per day, and the operating life of the landfill. Therefore, as population increases, the amount of waste accepted by landfills also increases. In large settlements, larger areas are required for the effective storage and processing of waste. As a facility that must operate for a long time, the size of the site allows for full acceptance of the waste generated during its future operating life. Organizing landfills in a larger area provides the necessary space for building a comprehensive infrastructure.

The area of the currently used landfill in the Dangara District is 15 ha. The size of this area may be sufficient to store waste. However, if the population in the area increases or if there is a need to store new waste, the size of the site will require expansion.

The size of a landfill site is important to determine its efficiency, environmental safety, and economic efficiency. Landfills with large areas are more efficient and provide space for all the systems necessary for proper waste management. Therefore, empty areas less than 30 ha were not considered, and larger areas were assigned higher weights.

RESEARCH RESULTS AND DISCUSSION

Digitization of the study area through multilayer analysis

Digitization of geographic data through multilayer analysis is one of the most advanced methods widely used in geographic information systems (GIS). The overlay of cartographic data in GIS is one of the most effective and widespread tools that allows for in-depth and systematic analysis of the study area. This approach allows the creation of new maps by overlaying different thematic maps on top of one another.

The overlay process creates new datasets by combining the spatial features and attribute data. Tools, such as unions, intersections, symmetrical differences, clips, and erases, play a key role in this process. Using these tools, different data layers were combined and analyzed. This created the basis for a detailed and comprehensive digitization of the study area.

Multilayer analysis is performed in the “Layers” section of GIS programs, in which different thematic layers are arranged in a fixed order. This method facilitates spatial analysis, which in turn allows for a comprehensive study of the landscape, infrastructure, environmental status, and other aspects of the area.

Using satellite imagery and other data sources, the city of Kokand and its surrounding areas were digitized. An example of the buffer zones created by overlaying this area is presented in Fig. 11, demonstrating the practical results of this approach. These analyses are particularly important for urban planning, environmental monitoring, and strategic planning.

Creation of a constraint map and location of alternative sites

The process of developing maps for alternative landfill areas requires several geoprocessing tools. This process allows for the identification of areas that are suitable for the location of the landfill and are subject to constraints. In a GIS environment, in particular, the “Layers” system available in the ArcGIS software, it is easy to analyze areas based on different scenarios. This approach allows the creation of various buffer polygons and the analysis of their attributes.

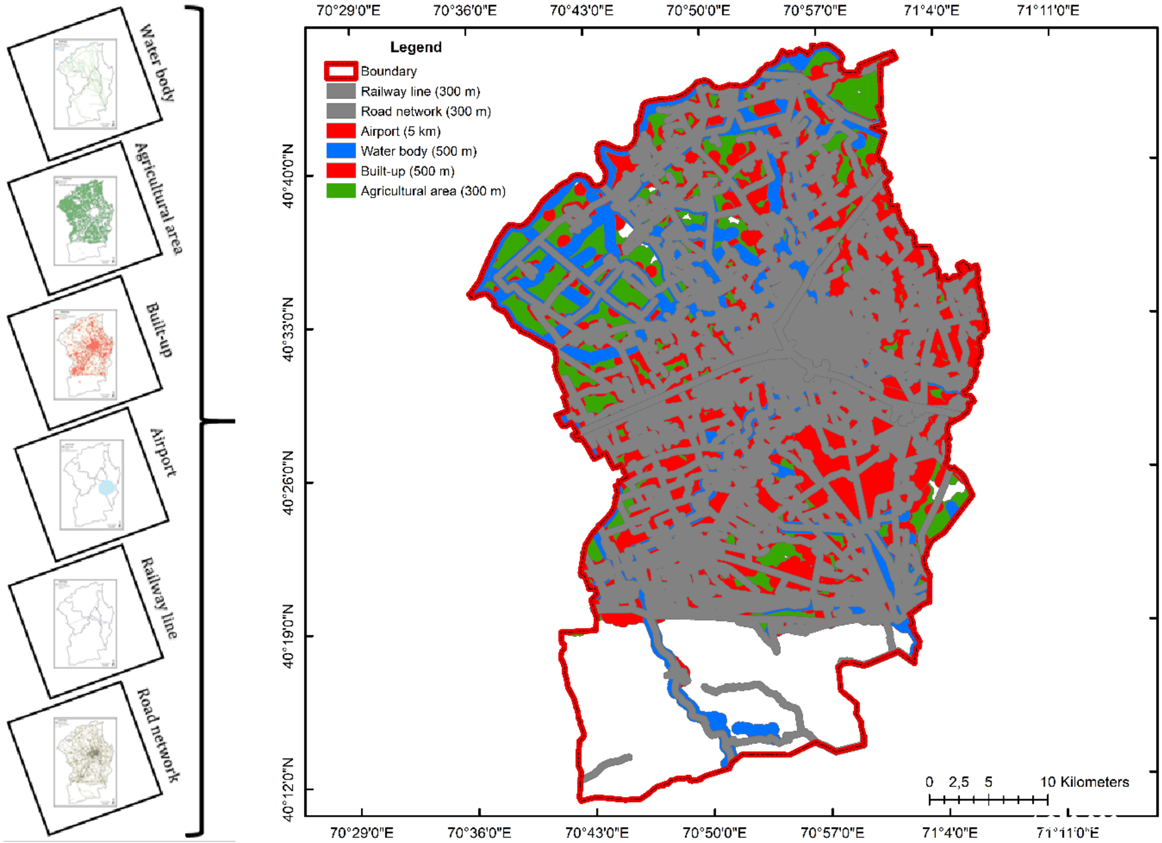

Fig. 11. Cartographic digitization of the city of Kokand and adjacent districts.
Source: Compiled by the author

Although there is no standard size for the minimum working area in the modern landfill location process, areas smaller than 30 ha were not considered suitable for analysis. Alternative sites were identified based on this criterion and territorial planning was conducted.

Based on the results of the analysis, three alternative sites (A, B, and E) are shown in Fig. 12. Three alternative sites (C, D, and F) were selected from the eastern and southern regions during the assessment. These areas were identified based on the boundary maps and served as reference points for the evaluation of alternative locations. Polygons D, E, and F were selected as alternatives to A–C by applying elevation and slope constraints to the initial MCE outcome, yielding topographically feasible polygons.

This method is highly effective in landscape planning, urban planning, and strategic decision making, ensuring the accuracy and reliability of the analysis process. Simultaneously, it allows for the integration of environmental, economic, and social factors in the selection of suitable areas.

Site Selection Using AHP and MCE Techniques

Six alternative sites were evaluated, based on nine indicators, to select the most suitable sites. The (AHP) is calculated using online AHP software[1] and was used to determine the weights of the factors. In this study, a pairwise comparison matrix (Table 4) was created based on Saaty and Vargas preference scales. Various previous studies [*Rahmat* et al., 2017; *Kamdar* et al., 2019; *Majid*, *Mir*, 2021] have used this method to weigh the factors controlling each site, and finally identify and map suitable areas for the site. The factors used to map the suitability of the site using

[1] Web resource: https://bpmsg.com/tag/ahp-weight-calculation/ (accessed 05.05.2025)

multi-criteria decision-making were given impact indices based on the local natural features of the study area and the evaluations of previous studies. The following steps were taken to determine the relative influence of each factor on the alternative locations of each polygon used in this study.

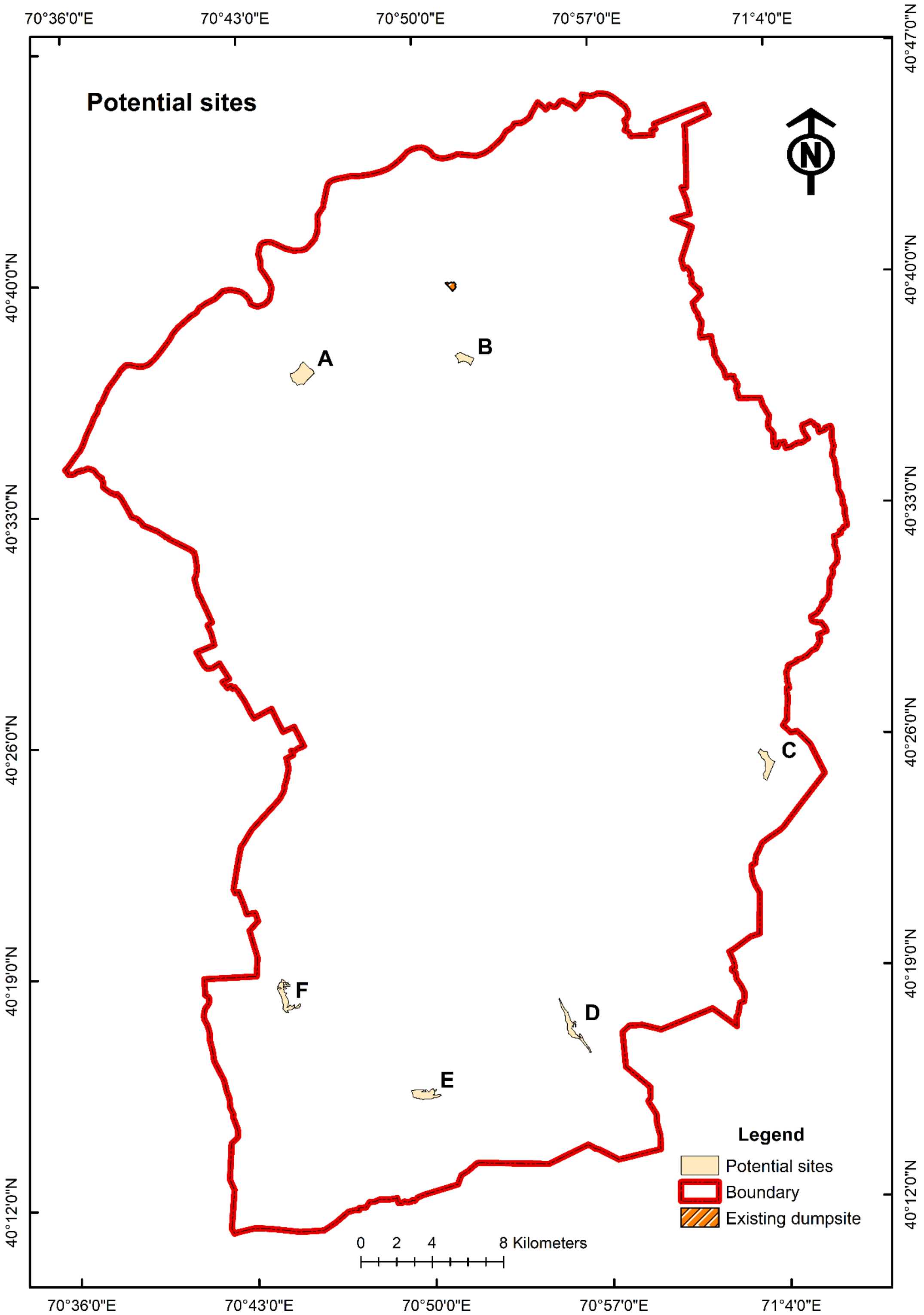

Fig. 12. Location of potential landfill sites

First step. Based on their relative importance, each factor was assigned a value from 1 to 9 to construct a pairwise comparison matrix (Table 4). On a scale of 1, 1 is equally important and 9 is extremely important.

Table 4. Pairwise comparison matrix

	Airport	Built-up	Water Body	Agricultural Area	Railway Line	Road Network	Slope	Elevation
Airport	1.00	7.00	6.00	5.00	4.00	3.00	2.00	2.00
Built-up	0.14	1.00	5.00	4.00	3.00	2.00	2.00	2.00
Water Body	0.17	0.20	1.00	3.00	2.00	2.00	2.00	2.00
Agricultural Area	0.20	0.25	0.33	1.00	2.00	2.00	3.00	3.00
Railway Line	0.25	0.33	0.50	0.50	1.00	2.00	3.00	3.00
Road Network	0.33	0.50	0.50	0.50	0.50	1.00	4.00	4.00
Slope	0.50	0.50	0.50	0.33	0.33	0.25	1.00	2.00
Elevation	0.50	0.50	0.50	0.33	0.33	0.25	0.50	1.00

Source: Compiled by the author using https://bpmsg.com/

Second step. Next, a normalized pairwise comparison matrix table (Table 5) was constructed by dividing each value in a column of the pairwise comparison matrix by the column sum.

Third step. In the third step, the influence of each factor is calculated (Table 5). This was performed by dividing the sum of each row in the normalized pairwise comparison matrix table by the number of factors (eight in this study).

Table 5. Normalized pairwise comparison matrix and calculated criteria weight for each factor

Factor number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**			
Factor name	**Airport**	**Built-up**	**Water Body**	**Agricultural Area**	**Railway Line**	**Road Network**	**Slope**	**Elevation**	**Sum**	**CW**	**CW (%)**
Airport	0.32	0.68	0.42	0.34	0.30	0.24	0.11	0.11	3.09	0.32	31.6 %
Built-up	0.05	0.10	0.35	0.27	0.23	0.16	0.11	0.11	10.28	0.17	17.2 %
Water Body	0.05	0.02	0.07	0.20	0.15	0.16	0.11	0.11	14.33	0.11	11.0 %
Agricultural Area	0.06	0.02	0.02	0.07	0.15	0.16	0.17	0.16	14.67	0.10	10.3 %
Railway Line	0.08	0.03	0.03	0.03	0.08	0.16	0.17	0.16	13.17	0.09	9.3 %
Road Network	0.11	0.05	0.03	0.03	0.04	0.08	0.23	0.21	12.50	0.10	9.8 %
Slope	0.16	0.05	0.03	0.02	0.03	0.02	0.06	0.11	17.50	0.06	5.9 %
Elevation	0.16	0.05	0.03	0.02	0.03	0.02	0.03	0.05	19.00	0.05	4.9 %

CW — criteria weight
Source: Compiled by the author using https://bpmsg.com/

Table 6 shows the final criterion impact for each site impact factor, which reflects the estimated relative impact of each factor on the sites in the study area: airports (31.6 %), built-up areas (17.2 %), water bodies (11.0 %), agricultural land (10.3 %), road networks (9.8 %), railway lines (9.3 %), and slope and elevation (5.9 % and 4.9 %, respectively).

After calculating the impact of each site impact factor, a robustness check was performed using the following equations to check whether the comparison was valid, and the consistency index (CI) was calculated using Equation (1), as described by Saaty [1987].

$$CI = \frac{\gamma_{max} - n}{n - 1} \quad (1),$$

where CI — the consistency index,
n — the number of factors compared in the matrix,
γ_{max} — the highest eigenvalue of the pairwise comparison matrix.

As proposed by Saaty [1987], the maximum eigenvalue (γ_{max}) of the comparison matrix is calculated using the following steps (Table 6):

1. Multiply each value in the column by the criterion effect (in the unnormalized matrix table).
2. Calculate the sum of the effects by adding the values in the rows.
3. The ratio of the sum of the effects to the corresponding criterion effect is calculated.
4. The average sum of the effects of these criteria was calculated.

Table 6. Calculating the consistency of pairwise comparison (CR = 0.03)

Factor number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**			
Factor name	**Airport**	**Built-up**	**Water Body**	**Agricultural Area**	**Railway Line**	**Road Network**	**Slope**	**Elevation**	**WSV**	**CW**	**WSV/CW**
Airport	0.32	1.20	0.66	0.51	0.37	0.29	0.12	0.10	3.57	0.04	11.32
Built-up	0.05	0.17	0.55	0.41	0.28	0.20	0.12	0.10	1.87	0.15	10.90
Water Body	0.05	0.03	0.11	0.31	0.19	0.20	0.12	0.10	1.10	0.13	10.06
Agricultural Area	0.06	0.04	0.04	0.10	0.19	0.20	0.18	0.15	0.95	0.09	9.29
Railway Line	0.08	0.06	0.05	0.05	0.09	0.20	0.18	0.15	0.86	0.32	9.18
Road Network	0.11	0.09	0.05	0.05	0.05	0.10	0.24	0.20	0.30	0.03	3.04
Slope	0.16	0.09	0.05	0.03	0.03	0.02	0.06	0.10	0.33	0.21	5.60
Elevation	0.16	0.09	0.05	0.03	0.03	0.02	0.03	0.05	0.33	0.03	6.75

WSV — weighted sum value
CW — criteria weight
Source: Compiled by the author using https://bpmsg.com/

Finally, to check the consistency of the comparison, the consistency ratio (CR) was calculated using Equation (2) proposed by [*Saaty*, 1987]:

$$CR = \frac{CI}{RI} \quad (2),$$

where CR — the coefficient of consistency,
CI — the consistency index,
RI — a random index that varies according to the number of factors in a pairwise comparison matrix.

If the CR is less than 0.10, the pairwise comparison matrix has an acceptable consistency. Otherwise, if the CR is greater than or equal to 0.10, the pairwise comparison is inconsistent and the comparison process should be repeated until the CR value is less than 0.10. In this study, CR was 0.03.

The consistency index (CI = 0.038) was calculated using Equation (1) and the consistency ratio (CR = 0.03) was calculated using Equation (2). The highest calculated value (γ_{max} = 8.26) and number of factors (n = 8) were used to calculate the CI. A random index (RI) of 1.41 was used to calculate CR. The random index (RI) varies depending on the number of factors and is 1.41 for eight factors. The calculated value of the correlation coefficient (CR) is 0.03 (3 %), which is less than 0.1 (10 %). Therefore, it is acceptable to use weighted overlay comparison.

As presented in Table 5, the weights of the different criteria were obtained using 28 pairwise comparisons. The results show that the distance from the airport has the highest weight, whereas area and height have the lowest weights. The airport weighs 31.6 % because of the possibility of bird strikes during the takeoff or landing of aircrafts, which can cause damage or even death. The landfill site should be located away from the airport area as these areas attract birds. Other important indicators include built-up areas, water bodies, and agricultural land. Therefore, three alternative landfills, A, B, and E, are recommended in this area (Fig. 13).

The smallest proposed landfill site is almost twice the size of the current landfill site. The proposed landfill “A” area is 95 ha, the landfill “B” area is 38 ha, and the landfill “E” area is 62 ha.

CONCLUSIONS

This study aims to identify alternative locations for new landfills in the city of Kokand and adjacent districts. The integration of GIS technologies and multi-criteria evaluation (MCE) techniques was chosen as the main method of this study. The influence of the selected indicators on the selection of landfill sites is as follows: airports (31.6 %), settlements (17.2 %), water bodies (11.0 %), agricultural land (10.3 %), road networks (9.8 %), railway lines (9.3 %), slope and elevation (5.9 % and 4.9 %, respectively). The estimated value of the correlation coefficient (CR) is 0.03 (3 %), which is less than 0.1 (10 %). Therefore, the use of weighted overlay comparison is acceptable. In the future, additional criteria such as groundwater depth and wind direction, as well as soil hydraulic properties, can be considered to improve this approach. The results of this study are not only scientifically valuable, but also provide practical guidelines for the sustainable development of the region. Due to the lack of accurate data on these indicators at present, they were not taken into account.

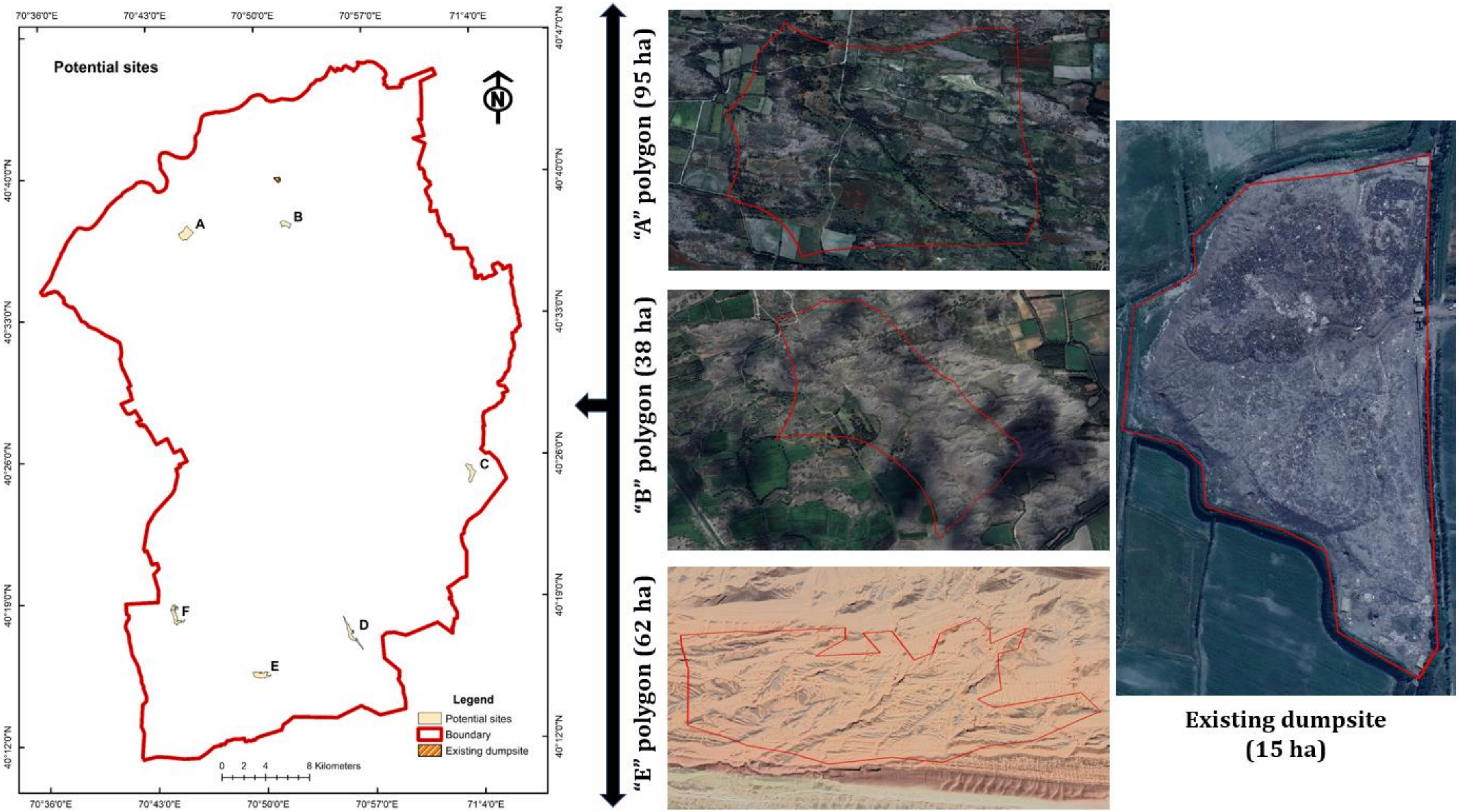

Fig. 13. Recommended landfill areas. Source: Compiled by the author

ACKNOWLEDGEMENTS

We would like to express our deep gratitude to all organizations and colleagues who supported, closely assisted, and provided valuable advice and technical assistance in the implementation of this study. In particular, we would like to thank the Ministry of Ecology, Environmental Protection, and Climate Change of the Republic of Uzbekistan for providing the data necessary for the study, as well as open platforms such as Sentinel-2 Land Cover Explorer and OpenStreetMap.

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