




Megacity solid waste disposal suitability mapping in Dhaka, Bangladesh: an integrated approach using remote sensing, GIS and statistics

Riad Arefin · A. T. M. Sakiur Rahman · Jayanta Das · Chowdhury Sarwar Jahan ·
Quamrul Hasan Mazumder · Ehab Gomaa · Ahmed K. Abd El Aal · Ahmed E. Radwan ·
Youssef M. Youssef 

Received: 29 February 2024 / Accepted: 27 August 2024
© The Author(s), under exclusive licence to Springer Nature Switzerland AG 2024

Abstract Selecting suitable Megacity Solid Waste Disposal (MSWD) sites is a challenging task in densely populated deltas of developing countries, exacerbated by limited public awareness about waste management. One of the major environmental concerns in Dhaka City, the world's densest megacity, is the presence of dumps close to surface water bodies resources. This study employed the Geographic Information System (GIS)-Analytic Hierarchy Process (AHP) framework to integrate geomorphological (slope and flow accumulation), geological (lithological and lineament), hydrogeological (depth to

groundwater table and surface waterbody), socioeconomic (Land use land cover, distance to settlement, road, and airport), and climatological (wind direction) determinants, coupled by land-use and hydro-environmental analyses, to map optimal dumps (MSWD_O) sites. The resulting preliminary (MSWD_p) map revealed 15 potential landfill areas, covering approximately 5237 hectares (ha). Combining statistical analysis of restricted areas (settlements, water bodies, land use) with AHP-based ratings, the MSWD_O map revealed two optimal locations (2285 ha). Additionally, the hydro-environmental analysis confirmed the

R. Arefin · C. S. Jahan · Q. H. Mazumder
Department of Geology and Mining, University
of Rajshahi, P.O. Box 6205, Rajshahi, Bangladesh
e-mail: riad.gmr@gmail.com

C. S. Jahan
e-mail: sarwar_geology@yahoo.com

Q. H. Mazumder
e-mail: qhm@yahoo.com

A. T. M. S. Rahman
Department of Environmental Sciences, University
of California, Riverside, CA 92521, USA
e-mail: shakigeo@gmail.com

J. Das
Department of Geography, Rampurhat College,
Rampurhat, West Bengal, India
e-mail: jayanta.daas@gmail.com

E. Gomaa
Department of Civil Engineering, College of Engineering,
Taif University, Taif, P.O. Box 11099, 21944, Saudi Arabia
e-mail: eegomaa@tu.edu.sa

A. K. Abd El Aal
Civil Engineering Department, Faculty of Engineering,
Najran University, Najran, Kingdom of Saudi Arabia
e-mail: ahmed_aka80@yahoo.com

A. E. Radwan
Faculty of Geography and Geology, Institute of Geological
Sciences, Jagiellonian University, Gronostajowa 3a,
30-387 Kraków, Poland
e-mail: radwanae@yahoo.com

Y. M. Youssef (✉)
Geological and Geophysical Engineering Department,
Faculty of Petroleum and Mining Engineering, Suez
University, Suez 43518, Egypt
e-mail: Youssef.ibrahim@pme.suezuni.edu.eg

unsuitability of northern sites due to shallow groundwater (<5.43 m) and thin clay, leaving 11 options excluded. Sites 12 (Zone A, 2255 ha) and 15 (Zone B, 30 ha), with deeper groundwater tables and thicker clay layers, emerged as optimal choices for minimizing environmental risks and ensuring effective long-term waste disposal. This study successfully integrates remote sensing, geospatial data, and GIS-AHP modeling to facilitate the development of sustainable landfill strategies in similar South Asian delta megacities. Such an approach provides valuable insights for policymakers to implement cost-effective and sustainable waste management plans, potentially minimizing the environmental risks to achieve Sustainable Development Goals (SDGs) 6, 11, 13, and 15.

Keywords Megacity solid waste disposal · Analytic hierarchy process · Land-use · Hydro-environmental · Sustainable development goals · Bangladesh

Introduction

Delta megacities, hubs of burgeoning urban-industrial development, offer vital socioeconomic opportunities in developing countries worldwide (Youssef et al., 2024). Unfortunately, these countries, with only 16% of the global population, generate 34% of the world's waste, posing significant environmental challenges in highly populated riverine areas (Van den Brandeler et al., 2019; Xu et al., 2019). Decades of rapid urbanization have worsened sanitation and solid waste (SW) management issues (Yin et al., 2021). Unmanaged SW disposal near agricultural lands and water resources cause diverse environmental and health risks due to hazardous pollutants, such as heavy metals, industrial waste, pesticides, and volatile organic compounds (Blight & Mbande, 1996; Lim et al., 2016; Santhosh & Babu, 2018; Akhtar et al., 2021). This disrupts surrounding aquatic and terrestrial ecosystems in riverine megacities (Tortajada, 2008; Youssef et al., 2024).

Globally, developing countries allocate 20–50% of municipal budgets to waste management (Guerrero et al., 2013), yet only collect 50–80% of generated waste due to high costs (80–95%) associated with collection and transportation (Abdel-Shafy & Mansour, 2018; Simion et al., 2013). Inadequate waste management, such as poor collection and disposal, poses significant environmental threats in delta megacities like

Cairo in the Nile Delta (Abdallah et al., 2020; Fahmi & Sutton, 2010), Dhaka in the Ganges–Brahmaputra delta (Ahmed & Rahman, 2000; Chowdhury & Afza, 2006; Yin et al., 2021), Bangkok in Chao Phraya Delta, Karachi in Indus delta (Soudani et al., 2024), and Mumbai in western Indian deltas (Iyer, 2016; Shah, 2021). South Asia, the largest waste-generating region globally (Kaza et al., 2018), produces around 70 million tonnes annually, with 426 million residents (Hoorweg & Bhada-Tata, 2012). In 2014, Bangladesh generated 23,688 tons of urban solid waste per day, with Dhaka accounting for 6,026 tons daily (Waste Concern, 2014). Within these challenges, delineating Megacity Solid Waste Disposal (MSWD) suitability sites is essential for achieving Sustainable Development Goals (SDGs), including 6 (clean water and sanitation), 11 (cultivating sustainable cities and inclusive communities), 13 (climate action), and 15 (conserving terrestrial ecosystems) in these metropolises (United Nations, 2018; Xu et al., 2019; Bilgilioglu et al., 2022).

Analyzing MSWD suitability requires considering various factors, including geomorphological, geological, hydrogeological, socioeconomic, and climatological conditions (Beskese et al., 2015; Santhosh & Babu, 2018). Traditional methods are limited, and integrating Remote Sensing (RS) and Geographic Information Systems (GIS) integration is imperative is essential for identifying potential MSWD sites (Halvadakis, 1993; Bilgilioglu et al., 2022). The multispectral Landsat series serves as a pivotal resource for mapping Land Use and Land Cover (LULC), enabling the delineation of human activities, socioeconomic aspects, and environmental conditions (Elmahdy & Mohamed, 2016; Youssef et al., 2021). Satellite-derived Digital Elevation Models (DEMs) have undoubtedly facilitated the acquisition of precise geomorphological information, encompassing topography, stream networks, and flow patterns (El-Aal et al., 2024; Embaby et al., 2024; Abu El-Magd et al., 2024). Noteworthy, the integration of Landsat and DEM imagery with subsurface (lithological and hydrogeological) datasets in GIS has recently improved our understanding of the near-surface environment, including pollutant accumulation and contaminant infiltration in the topsoil (Khalil et al., 2022; Youssef et al., 2021).

Diverse GIS-based Multi-Criteria Decision Analysis (MCDA) techniques, such as Weighted Linear Combination (WLC), Analytical Hierarchy Process (AHP), and fuzzy logic overlay, have been widely

employed to determine optimal SW disposal locations (Beskese et al., 2015; Lim et al., 2016; Paul & Ghosh, 2022). Among these, the AHP excels in structuring expert judgment through pairwise comparisons, producing a list of factors weighing (Saaty, 1980). Yesilnacar et al. (2012) found that WLC may not always be suitable due to rapid parameter changes. Bilgilioglu et al. (2022) utilized a GIS-integrated AHP approach for landfill site selection, demonstrating its effectiveness in the densely populated regions. As a result, several studies have successfully employed AHP to select sustainable SW disposal sites across various

regions of the world, i.e., Cao et al. (2006), Paul et al. (2014); Khan & Samadder (2015); Sam and Steven (2017); Ali et al. (2017); Tercan et al. (2020); Bilgilioglu et al. (2022); Paul and Ghosh (2022).

In the context of South Asia, the Ganges–Brahmaputra area is the most populous delta, hosting over 150 million people across Bangladesh, Bengal, and India (Chakraborty et al., 2021; UNDESA/PD, 2019; Edmonds et al., 2020). Dhaka City, the capital of Bangladesh (Fig. 1a), houses over 19% of this population and experiences a rapid growth rate of 37% (Rahman et al., 2020; Razia et al., 2023), making it on of

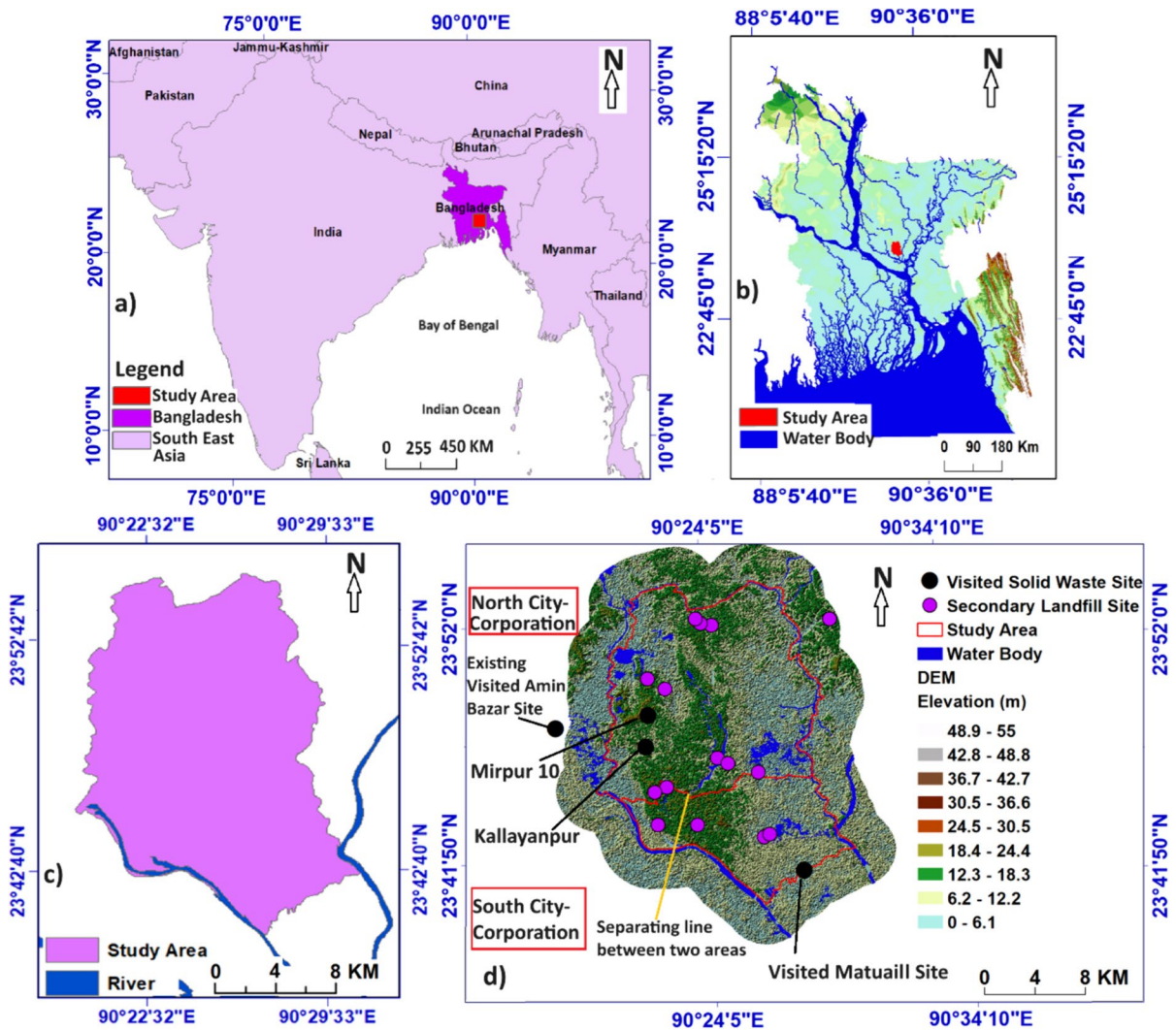


Fig. 1 a Location of the study area; b Elevation map displays Bangladesh country in the southern part of Asia, c Administrative map of Dhaka metropolis in the middle part of Bangladesh

showing the capital city (light green polygon) boundary, and (d) the location of the study area, as well the current locations of Solid Waste (SW) disposal site by black points

the most world's densest megacities (Demographia, 2019). Dhaka's metropolitan area experienced significant growth in 2020, with a population of 21,006,000, reflecting a 3.56% increase from 2019 (Yin et al., 2021). This population rumble places significant strain on waste management infrastructure and resources, driven by escalating food demands and consumption patterns, leading to extraordinary challenges for sustainable SW disposal (APO, 2007; Streatfield & Karar, 2008; Yin et al., 2021). Typically, the waste management system is community-based in the city, lacking involvement from the scientific community in the planning and mitigation efforts (Ahmed et al., 2018; Salam, 2000; Yousuf, 1996). For example, Dhaka residents generate approximately 4632 tons of waste daily (Rahman & Kashif, 2009), with an average of 40% of the generated waste remaining uncollected (Islam, 2016). Ahmed and Rahman (2000) and APO (2007) indicate that annually, around 1.65 million tons of solid waste is produced from households, industries, and growth centers in Dhaka, translating to approximately 0.29 to 0.60 kg/person/day. Given Dhaka's population exceeding 10.2 million, a comprehensive study of this area is imperative for informed decision-making (Fig. 2).

Several researchers therefore studied waste disposal management strategies and rehabilitation approaches in the Dhaka megacity, i.e., Yousuf (1996), Salam (2000), Chowdhury and Afza (2006), Zahur (2007), Tania (2014), Islam (2016), Ahmed et al. (2018), and Yin et al., 2021. On a local scale, Hasan et al. (2009) developed an integrated fuzzy set theory and WLC techniques in a GIS to improve landfill mapping in three districts, namely Dhaka, Narayanganj, and Gazipur. Islam et al., (2016) utilized a GIS-based optimization scenario to identify optimal relocations for the insufficient waste collection containers and design more efficient collection routes in Mirpur-Pallabi in northern Dhaka City. Recently, Akther et al. (2019) integrated MCDA and GIS techniques to find suitable SW sites considering environmental, social, and economic determinants in a zone of Dhaka. Despite these efforts, AHP-based GIS modelling has not been entirely successful in pinpointing suitable MSWD sites for the growing population in Dhaka. This research gap highlights the urgent need for holistic and data-driven techniques to effectively address solid waste disposal in this megacity. To this end, this work

typically considers the impact of both surface (socioeconomic, geomorphological, and climatological) and subsurface (lithological and hydrogeological) factors by integrating site suitability with a land-use and hydro-environmental evaluation analysis. The current research, therefore, aims to: (1) find out suitable sites for the MSWD using WLC; and (2) defining the optimal future waste disposal locations considering the hydro-environmental aspects and related problems in Dhaka city.

Study area characteristics and environmental challenges

The study area, situated in the central region of Bangladesh, encompasses the Turag, Balu, Lakhya, Shitalakshya, and Burigonga rivers; covering a total area of 306 km² (Fig. 1b). It falls within the North and South City Corporations of Dhaka City (Abir et al., 2021), which is situated between latitudes 90°16'13" -90°33'86" E and longitudes 23°56'44" -23°37'27" N (Fig. 1c). The proposed study area within the Madhupur tract is geologically significant due to its uplifted position relative to surroundings, the Enachulen fault structure, and lineaments influencing river flow (Alam et al., 1990). These features indicate ongoing tectonic activity (Maitra & Akhter, 2011). Additionally, the area's aquifer is recharged by nearby rivers during monsoons (Hasan et al., 1999). Kamal and Midorikawa (2006) produced a geomorphological map of Dhaka city using aerial photographs from 1954 (scale: 1:40000), incorporating information from fill-thickness, boreholes, and an old topographic map (see Fig. 3). The delineation revealed eighteen geomorphic units, with thirteen of them covering 65% of the area, necessitating landfill practices for urban development. These units represent the natural soil conditions or surface geology of Dhaka, with minimal anthropogenic intervention. The study area experiences a tropical climate characterized by hot, wet, and humid conditions, with distinct monsoon seasons being a prominent feature. The rainfall is so high that it ranges from 1942 to 2059 mm (Arefin, 2020). In the study area, the minimum temperature typically reaches 18 °C in January, while the maximum temperature peaks at 29 °C in August.

Notably, the city has exhibited rapid expansion, extending even into low-lying geomorphic units



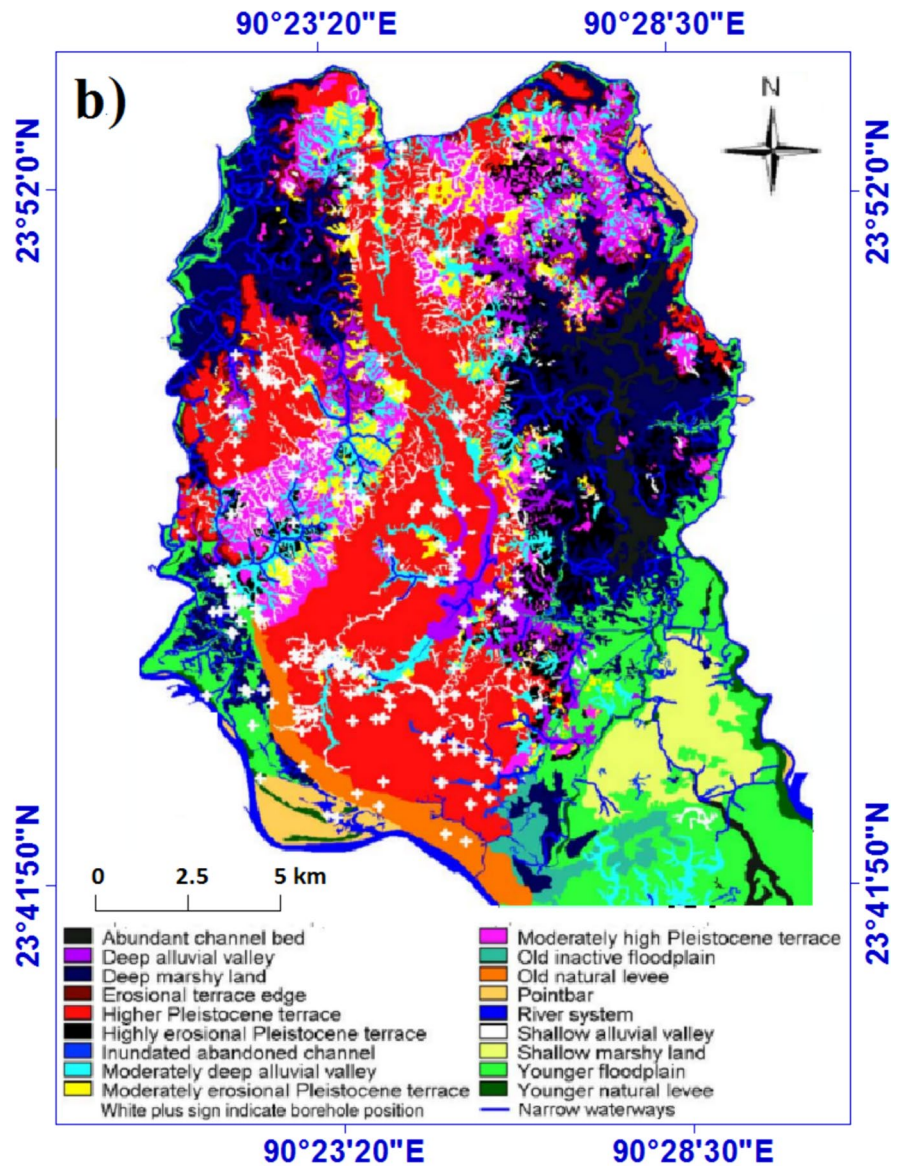
Fig. 2 Some collected photos during field observations in Dhaka city describing **a)** Solid waste was traditionally collected from households in the Kallyanpur region (Date: 22.10.2022), **b)** Unmanaged solid waste disposal practices near the Roadside In-Mirpur-10 (Date: 18.11.2022), **c)** Amin Bazar waste disposal site was designed as a landfill in the western part of Dhaka city (Date: 27.10.2022), **d)** Initiative of power

generation 42.5MW at Amin Bazar waste disposal site was designed as a landfill in the western part of Dhaka city (Date: 25.05.2024), **e)** the Matuail landfill site beside the building (Date: 20.12.2022), **f)** Kallyanpur wastewater canal was established to transport both domestic and industrial water (Date: 22.10.2022)

through fill practices since 1960. Dhaka, for instance, has a significant informal waste sector, with an estimated 1.7% of its population working in this sector (Wilson, 2010). The researchers also categorized fill sites into four classes based on the thickness of the fills. The Amin Bazar and Matuail landfill areas, located in the northwest and southeast, respectively, serve as the current dumping sites. The Amin Bazar site is located 7 km away from the city boundary area, and therefore, it is not included in this study. Based on our field observations, SW has been collected from the

Kalabagan, Dhanmondi, Banani, Gulshan, Baridhara, and Uttara residential areas by poor private management (Fig. 2a). Local transports, such as rickshaws and vans, collaborating to collect waste from houses to municipal containers is a promising approach to SW management (Fig. 2b-c). A 42.5-megawatt (MW) waste-to-energy (WtE) project was developed at the Amin Bazar under Savar Upazila landfill site in western Dhaka City, adjacent to agricultural land (Fig. 2d), generating large amounts of gas for power production (Toha & Rahman, 2023). Greenhouse gas emissions

Fig. 3 A geological map showing the surficial lithological and geomorphological units in the Dhaka region (Kamal & Midorikawa, 2006)



from the plant are estimated at 205.18–293.87 kilotonnes per year, totaling 5.13–7.35 million tonnes over its operation period. GHGSat (satellite-based and aerial remote sensing technology and emission) data indicates the site emits 35.04 kilotonnes of methane annually (Amin, 2021). However, direct measurements show 19.02 Gigagrams (Gg)/year, while the Land-GEM-V-3.02 (SP1) model estimates 25.95 Gg/year of methane emissions (Toha & Rahman, 2023). The current Matuail landfill areas (south east side of Dhaka city)—neglecting the buffer zones from urban

settlements and infrastructures—were designed to manage the dumping process (Fig. 2e). The wastewater canal in the Kallayanpur area, west side of the Dhaka city, is used as a sewerage line, as shown in Fig. 2f.

Datasets and methodology

This study employed diverse data sources to create a comprehensive framework for evaluating potential MSWD sites in Dhaka City. Table 1 outlines

Table 1 Data and relevant sources for the study

Layers	Sources
Slope	STRM-DEM from USGS Earth explorer of (30 m×30 m)
Flow accumulation	
Soil type	Geological Survey of Bangladesh
Lineament	Khan and Samadder (2015)
Land-use	Landsat 8 (OLI) mission of 2014 from USGS Earth explorer of (30 m×30 m)
Distance from settlement	
Distance from roads	
Distance from water bodies	
Distance from airport	
Depth to groundwater	Bangladesh Water Development Board (BWDB)
Wind direction	Bangladesh Meteorological Department (BMD)

the datasets utilized in this study, along with their respective sources. The Dhaka GIS database was built using accessible satellite (Landsat-8 and SRTM) imagery, groundwater well data, and supplementary datasets such as topographic sheets and local administrative maps. All thematic

images were co-registered to a common projection (WGS1984, zone 46N) using the ArcMap software. An integrated five-step approach within the GIS environment was implemented to achieve the research aims (Fig. 4), which included the following (Table 2):

Fig. 4 Flow chart for the solid waste landfill site selection

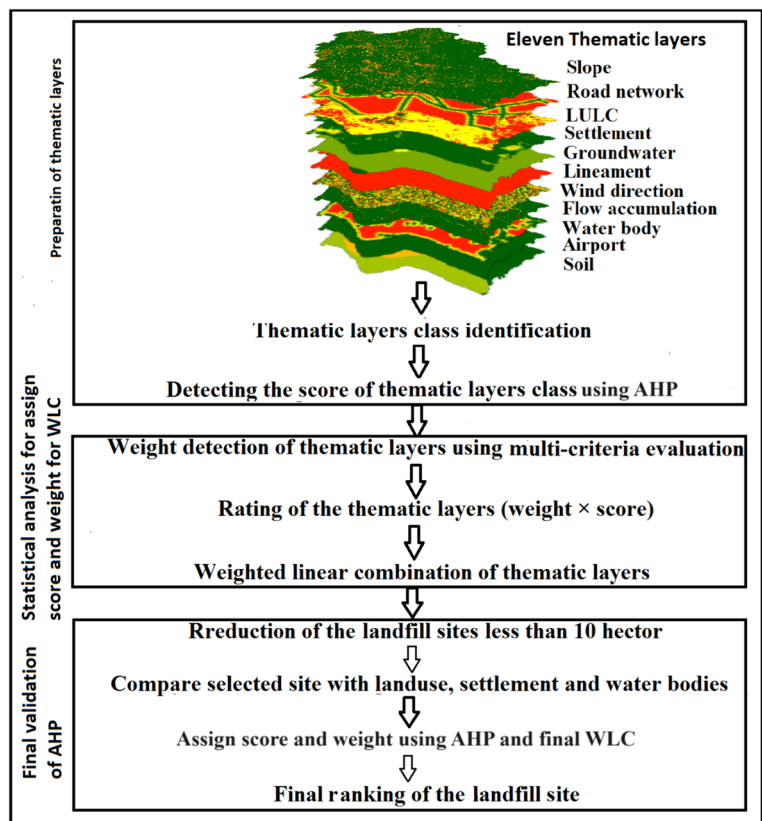


Table 2 Relative class rate scale according to Saaty (1980)

Definition	Equally important	Extremely less important	Strongly less important	Less important	Moderately less important	Moderately important	Strong important	Very strong	Extremely important
Intensity of Importance	1	2	3	4	5	6	7	8	9

Thematic mapping and classification of controlling factors

Following the comprehensive literature review, eleven controlling factors were selected for this work: slope, flow accumulation, soil type, lineaments, LULC, distance from roads, distance from settlements, distance from airports, distance from water bodies, depth to groundwater, and wind flow. The score of the thematic layers classes was chosen from 1 to 5 according to their importance (Khan & Samadder, 2015; Mussa & Suryabhadgavan, 2019; Santhosh & Babu, 2018). A score of 1 is designated for the category deemed suitable, while a score of 5 is allocated for the class considered comparatively less suitable, as suggested in the literature review (see Table 3).

Topographic factors: The shuttle radar topography mission (SRTM)-DEM data were acquired with a spatial resolution of 30 m. The spatial distribution of the surface elevation (Fig. 1c), slope, aspect, and flow accumulation maps were determined using the following steps: (1) a mosaic DEM image was created using ArcMap; (2) sinkholes were corrected by filling their elevation levels with those of their neighbors; (3) a flow direction map was generated from the resulting filled image using the eight-direction algorithm (D8). The flow accumulation raster imputes the cell number of the stream flow path. It also determines the size of the flow path after precipitation. The relationship between runoff and peak discharge can be determined from this raster. In this study, the slope and flow accumulation maps were classified into five classes following the classification scheme proposed by Khan & Samadder (2015), (see Fig. 5).

Climatological factors: Wind direction was obtained from the Bangladesh Meteorological Department (BMD), to assess its impact on odor dispersion from the landfill site. Since prevailing winds can carry

odors, minimizing the impact on settlements is crucial. Aspect and wind directions are interconnected with the flow path, as indicated by Şener et al. (2010). Therefore, the resulting aspect map from SRTM-DEM was utilized to enhance the classification of the wind direction map, categorizing it into north (N) to north-east (NE), south-west (SW) to west (W) to north-west (NW), east (E), south-east (SE), and flat to south (S) for the area (Fig. 5c).

Geological factors: The type of soil underlying SW dumpsites can significantly influence how contaminants leach into the underlying aquifer, potentially leading to water quality degradation and associated health risks (Gemail et al., 2017). The official soil map was obtained from the Geological Survey of Bangladesh to identify the soil types in the study area (Fig. 6a). Lineament is a geological structure that lies just below the weathered soil surface and acts as a conduit between surface water bodies and the aquifer (Gemitzi et al., 2007; Mussa & Suryabhadgavan, 2019). In this work, the lineament raster map was obtained from Khan & Samadder (2015), which was later classified using multi-buffering tools in ArcMap (Fig. 6b).

Socioeconomic factors: The LULC map was produced from Landsat 8 (OLI) (<https://earthexplorer.usgs.gov/>, acquired in February 2014) using the Maximum likelihood method. Preprocessing of the Landsat OLI, including radiometric and atmospheric corrections, was performed using the calibration and dark object subtraction tools in ENVI 5.1 software (Chavez, 1988). After that, the LULC map was produced by using the Maximum likelihood method. Six LULC classes were determined, namely vegetation, sand bar, water, open land, buildings, and roads (Fig. 7a). The accuracy of the LULC classification was verified using Google Earth imagery, which stood at 87%. To safeguard urban and economic projects from environmental hazards, landfill sites should be situated at a

Table 3 Thematic layers class range and their score and final rate

Layers	Class range	Score	Rate	Reference
Slope (SL)	> 8°-12°	1	0.198	Khan & Samadder (2015); Mussa and Suryabhagavan, (2019)
	> 12°-16°	2	0.396	
	> 4°-8°	3	0.594	
	0°-4°	4	0.792	
	> 16°	5	0.99	
Flow accumulation (FA)	0–600 cell	1	0.034	Khan & Samadder (2015)
	600–2500 cell	2	0.068	
	2500–6000 cell	3	0.102	
	6000–15000 cell	4	0.136	
	15,000–318867 cell	5	0.17	
Soil type (ST)	Madhupur clay residuum	1	0.014	Gemail et al. (2017)
	Marsh clay and peat	2	0.028	
	Alluvial silt and clay	3	0.042	
	Alluvial silt	4	0.056	
Distance from lineament (DL)	0–100 m	5	0.31	Khan & Samadder (2015); Demesouka et al., (2014)
	100–200 m	4	0.248	
	200–300 m	3	0.186	
	300–400 m	2	0.124	
	> 400 m	1	0.062	
Distance from water (DW)	0–100 m	5	0.735	(Khan & Samadder, 2015)
	100–200 m	4	0.588	
	200–300 m	3	0.441	
	300–400 m	2	0.294	
	400–500 m	1	0.147	
Groundwater table depth (GwT)	13.6–20.3 m	5	0.41	Mussa and Suryabhagavan (2019)
	> 20.3–27 m	4	0.328	
	> 27–33.7 m	3	0.246	
	> 33.7–40.4 m	2	0.164	
	> 40.4–47.1 m	1	0.082	
Land use/ Land cover (LULC)	Land	1	0.265	Ibrahim-Bathis and Ahmed (2016); Mussa and Suryabhagavan (2019)
	Vegetation	2	0.53	
	Settlement, road, water, sand bar	3	0.795	
Distance from the settlement (DS)	0–200 m	5	0.545	Khan & Samadder (2015)
	200–400 m	4	0.436	
	400–600 m	3	0.327	
	600–800 m	2	0.218	
	> 800 m	1	0.109	
Distance from road (DR)	100 m	5	0.125	Şener et al. (2010); Khan & Samadder (2015)
	200 m	4	0.1	
	300 m	3	0.075	
	400 m	2	0.05	
	500 m	1	0.025	

Table 3 (continued)

Layers	Class range	Score	Rate	Reference
Distance from the airport (DA)	0–200 m	5	0.09	(Khan & Samadder, 2015)
	200–400 m	4	0.072	
	400–600 m	3	0.054	
	600–800 m	2	0.036	
	800–1000 m	1	0.018	
Wind flow (WF)	N to NE	1	0.047	(Khan & Samadder, 2015)
	SW-W to NW	2	0.094	
	E	3	0.141	
	SE	4	0.188	
	Flat to S	5	0.235	

considerable distance from settlement areas, roads, and airports. All these factors were extracted from the LULC map using the clip option toolbox in ArcMap. Dhaka city boasts two airports: Hazrat Shahjalal International Airport, serving as the main gateway for international passenger flights, and Tejgaon Airport, primarily used by the Bangladesh Air Force for military operations. Consequently, the multi-buffer zones were created for landfill purposes to restrict human movement and development close to the landfill, building upon the approach proposed by Khan & Samadder (2015) for similar contexts. (Fig. 7 b-d).

Hydrogeological factors: SW releases harmful gases and leaches toxic solutes, posing a double threat to the environment through climate and water degradation (Lim et al., 2016). Groundwater Table (GwT) depth plays a pivotal role in evaluating environmental hazards associated with groundwater contamination (Khalil et al., 2022). The database includes GwT data and detailed lithological information up to 250 m, collected from over 1000 tubewells by the Bangladesh Water Development Board (BWDB, 1991). Five regular interval classes, i.e., 13.6 m to 20.3 m, 20.3 m to 27 m, 27 m to 33.7 m, 33.7 m to 40.4 m, and 40.4 m to 47.1 m, were created using the inverse distance weighting (IDW) interpolation method in ArcMap (Fig. 8b). Therefore, the landfill site must be away from the proximity of the groundwater well and surface water bodies. The water bodies raster map

was obtained from the LULC map. Additionally, the distance from water bodies was produced using multi-buffering tools in ArcMap (Khan & Samadder, 2015).

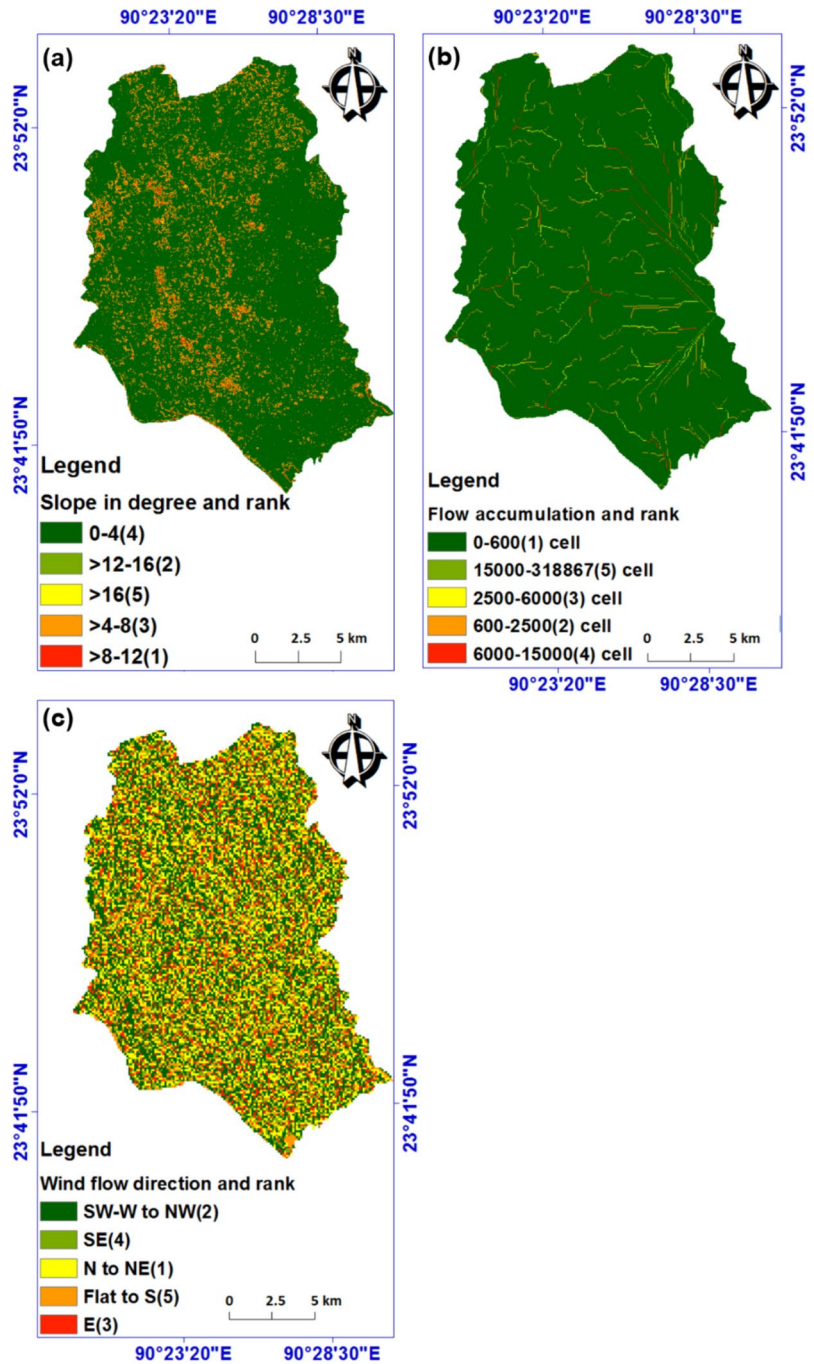
GIS-based multicriteria evaluation techniques

Homogenization and rating of input factors

In GIS modelling, multicriteria evaluation is a systematic process wherein a new criterion is derived by combining multiple criteria through informed judgments (Şener et al., 2010). The input data (criteria) of the same projection governed the MCDM. The homogenization step has become a standard process to build both suitability and susceptibility models (Aly et al., 2005). So, all the input factors were converted to raster layers of 30-m spatial resolution.

The decision is taken according to the input information of the eleven assigned rasters, then rearranged, and manipulation of the raster information cell by cell takes place according to the decision-making rules. In this work, eleven criteria have been evaluated, also known as Multi-Criteria Evaluation. According to Moeinaddini et al. (2010), well-defined criteria are crucial for transforming thematic maps into meaningful units within the MCDM framework. In this study, these criteria will guide the weighting of various topographical, climatological, socioeconomic, and hydrogeological

Fig. 5 Topographical and climatological factors of the study area showing (a) Slope, (b) Flow accumulation, and (c) Wind flow direction

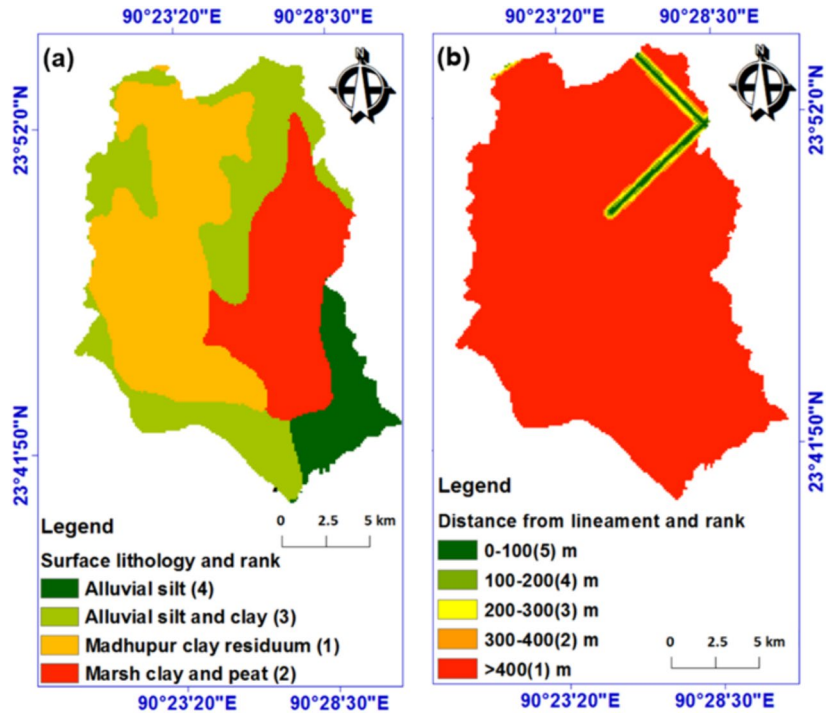


factors in the MSWD site selection process. The related thematic layers were arranged with numeric values between five (as the lowest suitable rate) and one (taken as the highest suitability rate). Later, these criteria were applied to the calculation of the MSWD sites on a GIS platform (Table 3).

Assessing criteria weight using AHP

The analytical hierarchy process is one of the functions of MCDA, where pairwise comparison matrices are used to understand the layer's importance (Saaty, 1977). The AHP technique helps to evaluate

Fig. 6 Geological factors of the study area showing (a) Lithological maps, and (b) Lineament map



each criterion since multiple important objectives are challenging to prioritize; therefore, it is helpful for the choice of importance. The weight of each layer is fixed using Saaty’s assumption (Saaty, 1977), where a normalized matrix is generated in comparison with the other criteria associated with the relative importance of the layers. Table 2 shows Saaty’s assumption that has been used for the layers criterion selection to calculate the WLC weightage.

The imputation of the MCDM procedure using AHP (Saaty, 1980) to detect thematic layers’ weight is described below (Table 4):

- (a) Impute the sum of each column of the pairwise comparison matrix (PWCM) as Eq. 1.

$$\text{Judgment Matrix}(P) = \begin{bmatrix} P_{11} & P_{12} & \dots & P_{1n} \\ P_{21} & P_{22} & \dots & P_{2n} \\ \dots & \dots & \dots & \dots \\ P_{n1} & P_{n2} & \dots & P_{nn} \end{bmatrix} \quad (1)$$

Where, P_{mn} = Indicator of the judgment matrix element.

- (b) Normalization by reciprocal of each element by dividing the column total as Eq. 2.

$$C_{ij} = \frac{P_{ij}}{\sum_{n=1}^{n_f} P_n} \quad (2)$$

Where, C_{ij} = normalized value of i^{th} element, P_{ij} = element of the i^{th} row and j^{th} column of the PWCM.

- (c) Impute the mean of each row of the normalized matrix to get the expected weight for the thematic layers as Eq. 3 (Table 5).

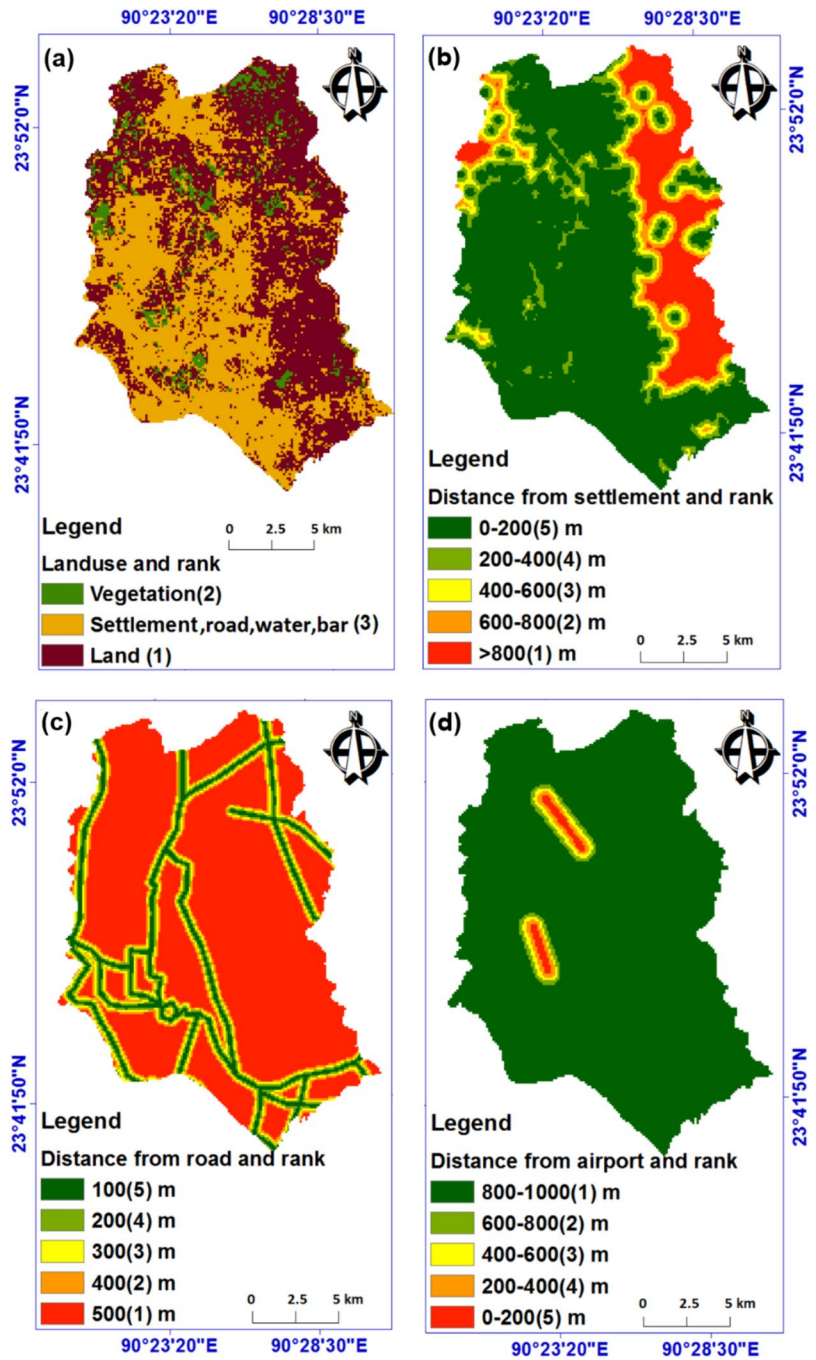
$$W = \frac{\sum_{i=1}^n C_i}{n} \quad (3)$$

where, W = Weight of the row (thematic layers), C_i = normalized value of i^{th} element, n = number of rows.

- (d) Consistency ratio (CR) was imputed (Saaty, 1980) to justify the consistency using Eq. (4) and Eq. (5).

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (4)$$

Fig. 7 Socioeconomic factors of the area with ranking: **a)** LULC map, **b)** Distance to settlement, **c)** Distance to road, and **(d)** Distance to airport



$$CR = \frac{CI}{CR}$$

(5) Where, λ_{max} = Prime eigen value = sum of the products of each vector and column summation, n = criteria, CI = index of consistency and RI = index of random inconsistency.

Fig. 8 Hydrogeological factors of the area with ranking: **a)** Surface waterbody and **b)** Depth of ground water table (GwT)

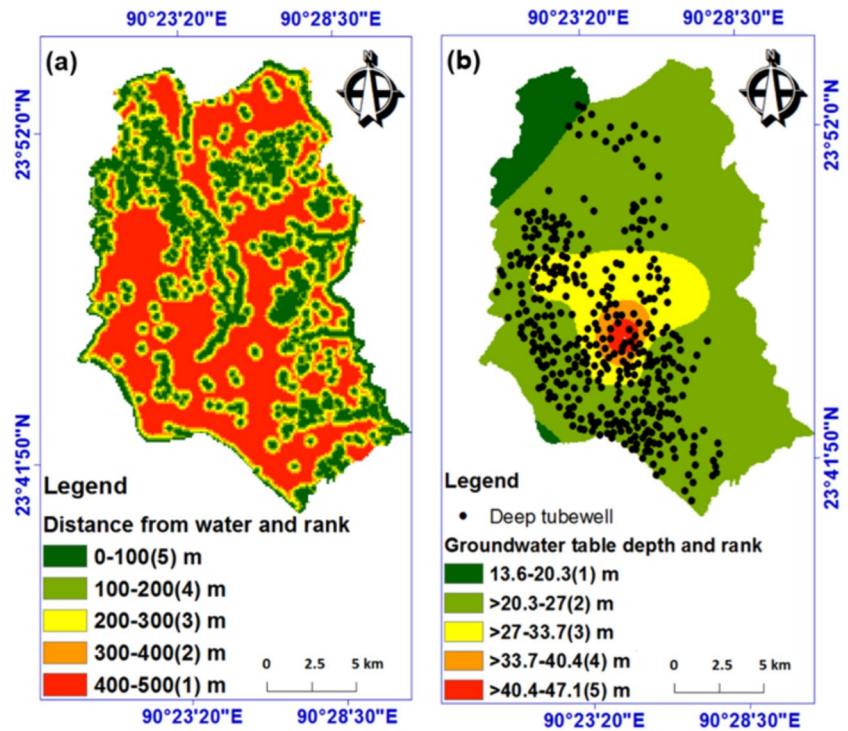


Table 4 Pairwise comparison matrix of the eleven thematic layers

Thematic layers	1	2	3	4	5	6	7	8	9	10	11
LULC (1)	1	-	-	-	-	-	-	-	-	-	-
(SL) (2)	1/2	1	-	-	-	-	-	-	-	-	-
(DW) (3)	1/3	1/2	1	-	-	-	-	-	-	-	-
(DS) (4)	1/4	1/3	1/2	1	-	-	-	-	-	-	-
(GwT)(5)	1/5	1/4	1/3	1/2	1	-	-	-	-	-	-
(DL) (6)	1/5	1/5	1/4	1/3	1/2	1	-	-	-	-	-
(WF) (7)	1/6	1/5	1/5	1/4	1/3	1/2	1	-	-	-	-
(FA) (8)	1/7	1/6	1/5	1/5	1/4	1/3	1/2	1	-	-	-
(DR) (9)	1/8	1/7	1/6	1/5	1/5	1/4	1/3	1/2	1	-	-
(DA) (10)	1/9	1/8	1/7	1/6	1/5	1/5	1/4	1/3	1/2	1	-
(ST) (11)	1/9	1/9	1/8	1/7	1/6	1/5	1/5	1/4	1/3	1/2	1

If the CR value becomes >0.10, then some comparison value needs to be readjusted so that it becomes <0.10 (Table 5).

Utilizing WLC for mapping the suitability of MSWD

The GIS mapping needs two constraints, such as rating and weightage for each involved controlling factor based on judgment standards (Pekkan et al., 2015). After assigning weights reflecting their relative

importance to establish the suitable landfill area, the scored layers were combined using a WLC approach. WLC is a widely recognized and popular method that has been applied in many urban suitability/susceptibility assessments through a linear function (i.e., Malczewski, 1997; Youssef et al., 2021). The preliminary MSWD map through the WLC was produced by assigning designed weights to all scored factors and evaluating the combined intersection for each class by the arithmetic overlay using Eq. 6 (Fig. 9a).

Table 5 Normalized matrix and weight of the eleven thematic layers

Thematic layers	1	2	3	4	5	6	7	8	9	10	11	Weight
LULC (1)	0.318	-	-	-	-	-	-	-	-	-	-	0.265
(SL) (2)	0.159	0.199	-	-	-	-	-	-	-	-	-	0.198
(DW) (3)	0.106	0.099	0.126	-	-	-	-	-	-	-	-	0.147
(DS) (4)	0.080	0.066	0.063	0.085	-	-	-	-	-	-	-	0.109
(GwT)(5)	0.064	0.050	0.042	0.042	0.060	-	-	-	-	-	-	0.082
(DL) (6)	0.064	0.040	0.032	0.028	0.030	0.047	-	-	-	-	-	0.062
(WF) (7)	0.053	0.040	0.025	0.021	0.020	0.023	0.037	-	-	-	-	0.047
(FA) (8)	0.045	0.033	0.025	0.017	0.015	0.016	0.018	0.029	-	-	-	0.034
(DR) (9)	0.040	0.028	0.021	0.017	0.012	0.012	0.012	0.015	0.024	-	-	0.025
(DA) (10)	0.035	0.025	0.018	0.014	0.012	0.009	0.009	0.010	0.012	0.020	-	0.018
(ST) (11)	0.035	0.022	0.016	0.012	0.010	0.009	0.007	0.007	0.008	0.010	0.017	0.014

Table 6 Area of landfill site obtained from the WLC

Selected site from WLC	Shape area (ha)
1	2175
2	99
3	28
4	157
5	11
6	195
7	14
8	22
9	10
10	13
11	11
12	2255
13	106
14	11
15	30

$$MSWD = \sum_{i=1}^n X_i \times W_i \tag{6}$$

Where, MSWD=The Megacity Solid Waste Disposal (MSWD) sites map, X_i =Criterion score, and W_i =weight assigned to each criterion.

Balancing MSWD management: hydro-environmental and health perspectives

Toward a sustainable MSWD suitability map, it is crucial to emphasize effective waste management systems regarding environmental and public health

preservations by considering hydro-environmental factors. To this end, the subsequent procedures were utilized:

1. Due to their limited capacity and potential logistical challenges, the preliminary Megacity Solid Waste Disposal (MSWD_p) sites smaller than 10 hectares (ha) were excluded from further analysis within the GIS environment (Table 6).
2. The MSWD_p was statistically compared with the constraints (settlement, surface water bodies, and land use patterns) factors (Fig. 10). This analysis aimed to validate the effectiveness of the proposed waste management system in considering these critical physical and environmental factors (Table 7).
3. The AHP calculations were conducted for the land use, water bodies, and settlement area to determine the influence of the selected landfill site on the final selection and ranking (Tables 7, 8, and 9).
4. The optimal Megacity Solid Waste Disposal (MSWD_o) site map of Dhaka city was obtained by multiple ranks of the MSWD_p sites with the AHP calculation weight of the land use, settlement, and water (Table 9). The resulting MSWD_o is classified based on the degree of suitability (Fig. 11), with the lowest value, equal to 1, assigned as the suitable site for landfill.
5. Afterwards, a more in-depth qualitative analysis was performed between the promising MSWD_o sites and three-dimensional (3D) hydro-stratigraphic models. The 3D hydro-stratigraphic units

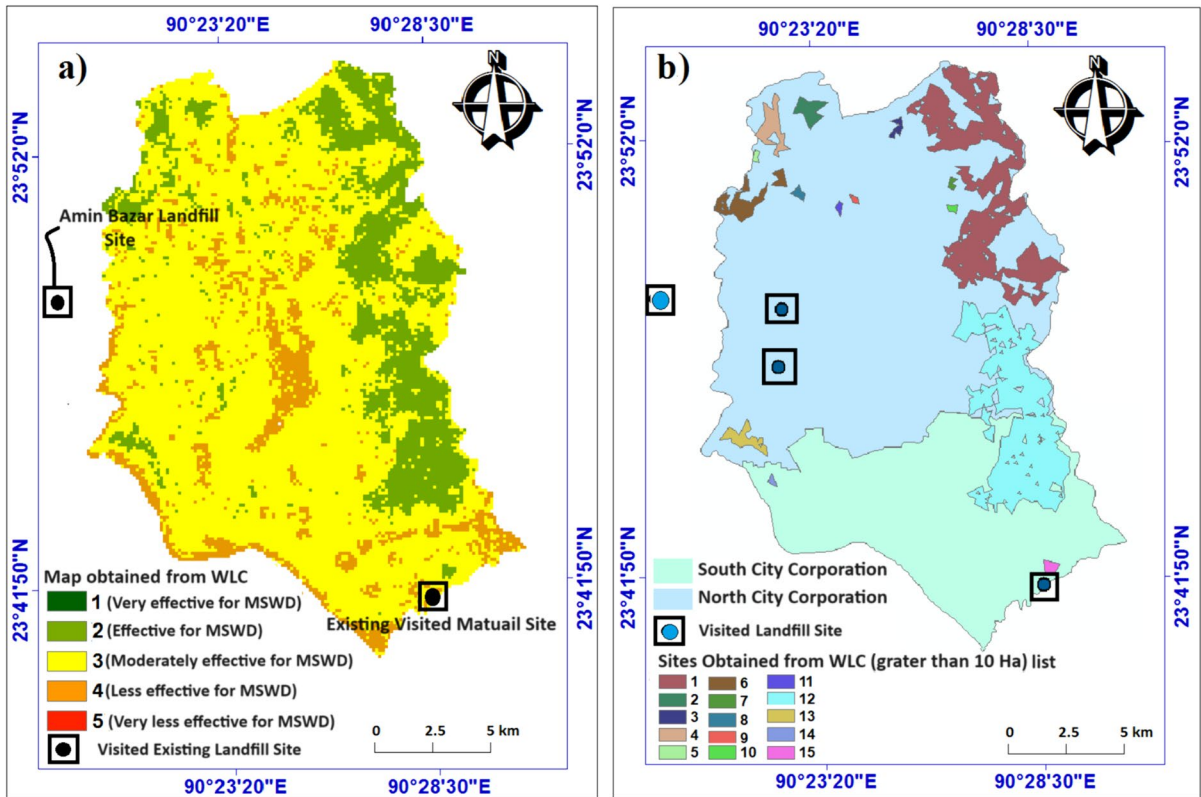
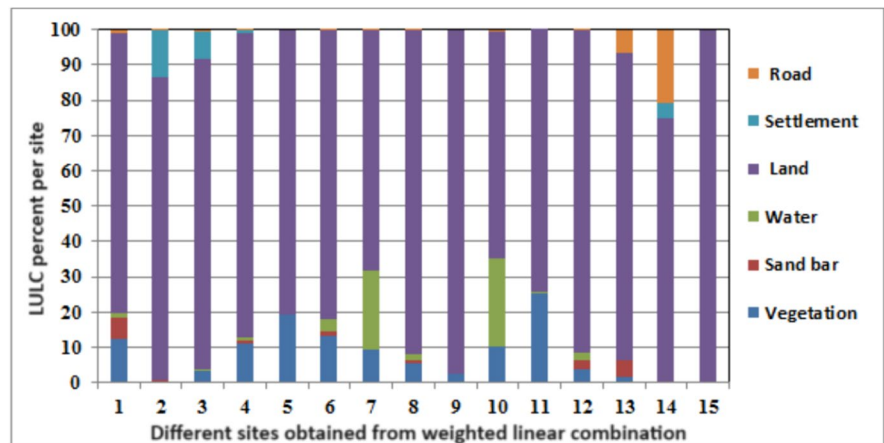


Fig. 9 The map displays (a) the suitability for MSWD sites using the WLC method, classified into five categories and (b) the preliminary Megacity Solid Waste Disposal (MSWD_p) sites obtained after removing areas less than 10 hectares

Fig. 10 The percentage area of Land Use and Land Cover (LULC) classes over the fifteen preliminary landfill sites



were evaluated — neglecting field observations and quantitative analysis — to investigate the contribution of clay aquitard thickness and depth to the MSWD₀ sites. The 3D model was gener-

ated from borehole lithological data using 3D gridding Voxel tools, applying the lithoblen- ding algorithm theory in the Rockworks package (Fig. 12a-c). The thickness of the clay layer was

Table 7 Pair-wise comparison for land use, settlement and water

Layers	Land use	Settlement	Water
Land use	1	-	-
Settlement	1/3 (0.33)	1	-
Water	1/6 (0.17)	1/4 (0.25)	1

Table 8 Normalized matrix from the pairwise comparison matrix

Layers	Land use	Settlement	Water	Rate
Land use	0.67	-	-	0.64
Settlement	0.22	0.24	-	0.27
Water	0.11	0.06	0.09	0.09

also created using the IDW interpolation technique (Fig. 12d-e)

Results and discussion

The current study has addressed a critical gap in the selection of effective solid waste disposal sites using GIS and MCDM for efficient management purposes in the Dhaka megacity. The following sections demonstrate the successful application of the GIS-based AHP and statistical approach to determine appropriate locations for MSWD from various and large spatial information in the delta megacities.

Characterization of controlling factors for MSWD

Eleven factors were used to select optimal urban landfill sites in the current study. These layers are associated with geomorphological, geological,

hydrogeological, climatological, and socio-economic aspects. Table 3 presents thematic layers with their respective classes, criteria, and standardized scores. Table 4 displays the PWCM for the eleven thematic layers, with criteria selection based on Saaty’s assumption (refer to Table 2). The results of thematic controlling factors were described in the following section:

Topographical factors

Topography defines the local and regional relief that provides an idea of groundwater flow (Gintamo, 2015). The sloping area of more than 20° was excluded (Şener et al., 2010), while the slope surface (8°–12°) was found to be suitable for dump sites (Khan & Samadder, 2015; Lin & Kao, 1998). In this study, the slope area between 8° and 12° was defined as more suitable for the landfill site than the steeper (> 12°) slope that permits high runoff and impurities that are mobile for longer distances from the source area (Mussa & Suryabhagavan, 2019). Thus, the score and rating for the slope map classes are as follows: 4 with a rate of 0.792 for 0°- 4°, 3 with a rate of 0.594 for > 4°- 8°, 1 with a rate of 0.198 for > 8°- 12°, 2 with a rate of 0.396 for > 12°—16°, and 5 with a rate of 0.99 for > 16°. Table 5 shows the normalized matrix and weight (0.198) of the slope map (Fig. 5a).

Concerning water flow, zones with high flow accumulation pose a risk of water pollution by solids and waste (Khan & Samadder, 2015). So, the large cell number zone is not suitable for MSWD, whereas the low cell number zone is highly suitable. In this study, the flow accumulation scores and rates were delineated across different ranges: 0–600 cells (rate 0.034), 600–2500 cells (rate 0.068), 2500–6000 cells (rate 0.102), 6000–15000 cells (rate 0.136), and 15,000–318867 cells (rate 0.17) (Fig. 5b and Table 3). Table 5 shows the weight (0.034) of this

Table 9 Shows the comparison of the fifteen sites concerning land use, settlement and water and the rank

	Selected site	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Layers Rank	Land use	12	11	8	3	6	9	10	7	2	13	4	5	14	15	1
	Settlement	1	15	14	3	4	5	6	7	13	8	12	2	9	11	10
	Water	1	3	4	14	6	7	8	9	10	15	11	2	12	13	5
	Overall rank	9	12	11	3	4	8	10	7	5	13	6	1	14	15	2

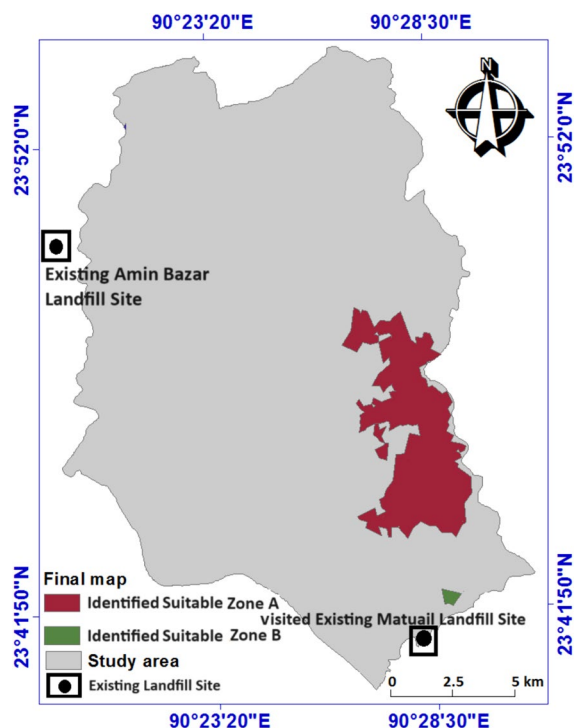


Fig. 11 The optimal future Megacity Solid Waste Disposal (MSWDOF) sites map of Dhaka city

raster. Figure 4h shows the flow accumulation map for the proposed area.

Climatic factors

Solid waste creates an odour that spreads with the wind direction. In the study area, the dominant wind direction is from the South (Fig. 5c). The hillsides facing N and NE directions experience limited wind flow throughout the year and are assigned a score of 1 (refer to Table 3). Aspects aligned with the prevailing wind direction throughout the year receive a higher score of 5. Therefore, city dwellers will be affected by the wind flow over the landfill site. Table 5 shows the weight (0.047) of the aspect map.

Geological factors

Lithology plays a crucial role in selecting suitable waste dumping sites, as highlighted by Rahmat et al. (2016). Surface lithology includes Madhapur clay residuum, marsh clay and peat, alluvial silt, and clay (Fig. 6a). Hazardous waste disposal in porous and

non-cohesive soils, i.e., clay residuum and peat, is particularly dangerous due to the elevated risk of contaminant leaching into aquifer, potentially impacting groundwater quality (Abu Salem et al., 2021; Alfay et al., 2010). In contrast, clay soil offers a natural barrier against contaminant leaching, significantly minimizing the risk of groundwater contamination (Abu Salem et al., 2021; Gemal et al., 2017). Consequently, Madhapur clay is considered suitable for waste disposal and assigned a score of 1 (Fig. 6a), whereas alluvial silt is considered less suitable and assigned a score of 4. Notably, Madhapur clay residue covers 38% (116 km², rate 0.014), marsh clay and peat occupy 24% (73 km², rate 0.028), alluvial silt and clay span 29% (89 km², rate 0.042), and alluvial silt encompasses 9% (28 km², rate 0.056). The weight of the soil type was 0.014 obtained from PWCM, as shown in Table 5.

Concerning geological structures, it is advisable to construct landfill sites away from areas susceptible to endogenic disturbances in the Earth, including faults, fissures, and joints (Mallick, 2021). According to Demessouka et al. (2014), a SW site needs to be selected at least 100–200 m apart from any weak zones (i.e., joints and faults). For the current study, the lineament raster was classified using 100 m multi-buffering that continued up to 500 m (Khan & Samadder, 2015). For MSWD, a distance of 500 m is considered suitable and assigned the value 1, whereas areas closer to 100 m are deemed less appropriate and assigned the value 5. The lineament map is classified into five regular interval classes (Fig. 6b), with scores and rates as follows: 5 with a rate of 0.31 for 0–100 m, 4 with a rate of 0.248 for 100–200 m, 3 with a rate of 0.186 for 200–300 m, 2 with a rate of 0.124 for 300–400 m, and 1 with a rate of 0.062 for distances exceeding 400 m (Table 3). The weight is obtained at 0.062 for the lineament map, as shown in Table 5.

Socioeconomic factors

Understanding the distribution of surface water bodies (lakes and rivers), vegetation, and other covers through LULC analysis is crucial for assessing the potential impact of SW disposal on water quality and aquatic ecosystems (Ibrahim-Bathis & Ahmed, 2016). Restricted areas, such as well points, rivers/streams, roads, built-up areas, and forests, should

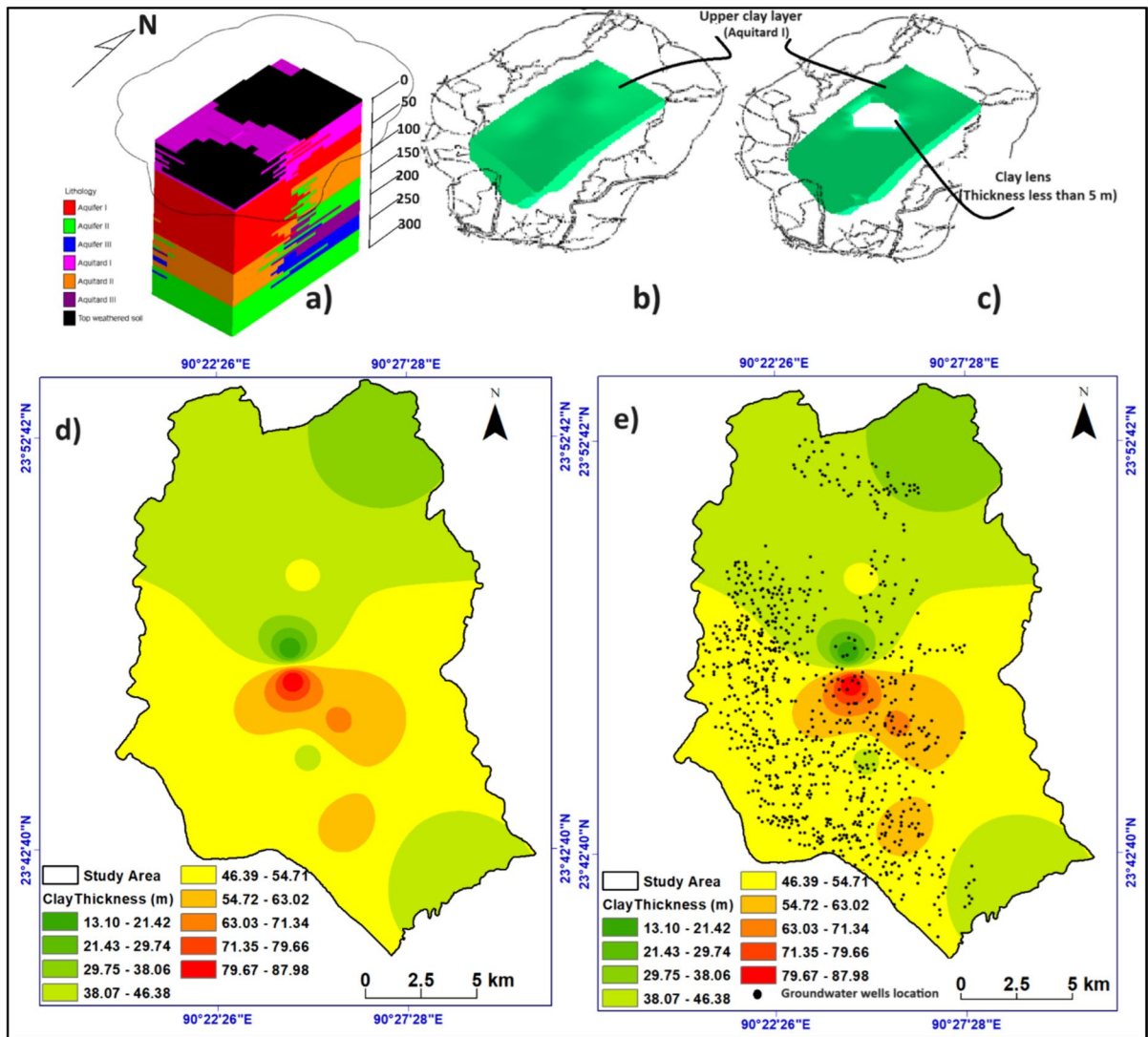


Fig. 12 a 3D view of Hydro-stratigraphic model of the study area, b 3D view of weathered and aquitard (Clay) zone thickness, c 3D view of weathered and Clay zone with thickness less than 5 m, d 2D view of Inverse Distance Weighting (IDW) interpolated clay thickness map, and (e) With the existing location of tubewell as shown in black color symbol

be avoided for SW dumping. On the other hand, bare lands are considered the most suitable option for SW disposal (Mussa & Suryabhagavan, 2019). The LULC map comprises vegetation covering 6% (20 Km²) area, sand bar covering 2% (6 Km²) area, water covering 6% (17 Km²) area, open land covering (barren land) 47% (145 Km²) area, buildings covering 33% (102 Km²) area, and roads covering 5% (16 Km²) area (Fig. 7a). Open land with scrub vegetation received a high suitability score (1) and a weight of 0.265 due to its availability for waste disposal.

Conversely, restricted areas (settlements, roads, water bodies, and sand bars) were excluded (score 3) to prevent water pollution and aquifer infiltration. The combined rate of these classes is 0.795. The weight of the LULC was 0.265 obtained from PWCM, as shown in Table 5.

Analysis of the LULC data revealed a remarkably high population density of over 41,000 people per Km² within the built-up (33% of the region) areas. This density is comparable to, if not exceeding, major metropolises globally, potentially placing

Analysis of the LULC data revealed a remarkably high population density of over 41,000 people per Km² within the built-up (33% of the region) areas. This density is comparable to, if not exceeding, major metropolises globally, potentially placing

it among the top contenders for the highest density based on readily available data (Demographia, 2019; Razia et al., 2023). Previous research shows that the landfill area should not be established within 1 km of the settlement area (Şener et al., 2010). Demesouka et al. (2014) also argued that the 500 m distance is suitable for landfill purposes. In the context of the settlement map, a 200 m multi-buffering process was applied, extending up to 800 m (Khan & Samadder, 2015). Figure 7b shows the distance from the settlement map and their classes. The distance from the settlement map was categorized into five classes with associated scores and rates as follows: 0–200 m (class 5, rate 0.545), 200–400 m (class 4, rate 0.436), 400–600 m (class 3, rate 0.327), 600–800 m (class 2, rate 0.218), and > 800 m (class 1, rate 0.109). PWCM provides a weight of 0.109 for this layer (Table 5).

To prevent adverse effects on public movement, Mussa and Suryabhagavan (2019) recommended a distance of over 4900 m from roads as suitable for landfill dumping. However, it is important to consider placing the landfill site closer to the road network, ideally within 200 m, to optimize cost-effectiveness (Şener et al., 2010). Herein, 100 m multi-buffer zones were created up to 500 m distance for SW purposes to avoid adverse effects on human movement. The road network map is classified, each assigned a score, rate, and distance as follows: 5 with a rate of 0.125 for 100 m, 4 with a rate of 0.1 for 200 m, 3 with a rate of 0.075 for 300 m, 2 with a rate of 0.05 for 400 m, and 1 with a rate of 0.025 for 500 m, as outlined in Fig. 7c and Table 3. The obtained weight for the road network map was 0.025 using PWCM (Table 5).

A constraint landfill buffer, ranging from 200 to 1000 m in five classes, was considered in this study (Khan & Samadder, 2015). This measure was taken to prevent the presence of birds in the vicinity, ensuring that it does not pose any obstacle to airborne vehicles (Moeinaddini et al., 2010). The distance up to 1 km from the airport is deemed more suitable and is assigned a score of 1. The distance to the airport map was classified into five distance classes with associated rates, as shown in Table 3: 0–200 m (rate 0.09), 200–400 m (rate 0.072), 400–600 m (rate 0.054), 600–800 m (rate 0.036), and 800–1000 m (rate 0.018). This layer was assigned a weight of 0.018 (Table 5).

Hydrogeological factors

Understanding the hydrogeological setting, including the depth of the aquifer, soil permeability, and distribution of water bodies, is crucial for predicting the movement of pollutants from landfills (Mekuria, 2006). The prominent water features for Dhaka city and its adjacent areas include rivers (Turag, Balu, Lakya, and Burigonga), lakes (Gulshan, Hatir-Jheel, and Dhanmondi), and ponds. The buffer zone of unsuitable sites from water bodies is classified into different scores and distance intervals: score 1 for 0–100 m (rate of 0.735), score 2 for 100–200 m (rate of 0.588), score 3 for 200–300 m (rate of 0.441), score 4 for 300–400 m (rate of 0.294), and > 400 m (rate of 0.147). A distance of 500 m from water bodies is considered suitable for SW site selection and is assigned a score of 1. The obtained weight was 0.147 for this layer, as shown in Table 5.

Figure 8b shows the GwT depth and groundwater pumping well map for the study area. The GwT depth ranges from 13.6 m in the northwestern part to 47.1 m in the middle parts. Substantial groundwater extraction of about 2.0 Mm³/day groundwater was observed from the Dupi-Tila formation of the upper Plio-Pleistocene age, where 563 deep tube wells belonged to BWDB and 2000 private tube wells were assigned for this purpose (Arefin & Alam, 2020; Arefin, 2020). Hence, MSWD sites should be away from the existing groundwater wells in the western and middle parts (Khan & Samadder, 2015; Mussa & Suryabhagavan, 2019). The scores, rates, and depth intervals are as follows: 5 with a rate of 0.41 for 13.6–20.3 m, 5 with a rate of 0.328 for > 20.3–27 m, 5 with a rate of 0.246 for > 27–33.7 m, 5 with a rate of 0.164 for > 33.7–40.4 m, and 5 with a rate of 0.082 for > 40.4–47.1 m (Table 3). Table 5 shows the weight (0.082) of the GwT depth map.

Megacity solid waste disposal (MSWD) site suitability mapping

To identify the MSWD site, the AHP was applied to the selected thematic layers to determine their importance. In the AHP calculation, weights assigned to each thematic layer were carefully determined considering their contribution to both environmental suitability and potential risks to human health. Experts in waste management and public health informed the

weighting process, ensuring a balanced approach that prioritizes both sustainable practices and community well-being. PWCM was conducted to produce the weight after assigning the rational environmental criteria, as shown in Table 4. Table 5 shows the normalized matrix where the value of each column drives the ratio of the column value divided by the corresponding column total. Finally, the weights are obtained by taking the average value of the row for each layer. The whole procedure has been narrated in the methodology section. The CR value for each AHP was kept below 0.1 for suitable weight assignment. According to the weightage of AHP model, the LULC has the highest value (0.265), followed in order of importance by SL (0.198), DW (0.147), DS (0.109), GwT (0.082), DL (0.062), WF (0.047), FA (0.034), DR (0.025), and DA (0.018), whereas the ST has the lowest weight value (0.014). Finally, the WLC method was applied to aggregate the selected thematic layer and generate potential MSWD sites using ArcGIS.

The area identified by WLC was classified into five suitability classes from very highly suitable (1) to unsuitable (5), as shown in Fig. 5a. The highly suitable area of class 2 is negligible; therefore, class 1 areas were taken into consideration for MSWD_p purposes. Additionally, the SW disposal sites with an area exceeding 10 hectares (ha) were deemed suitable for further analysis (Fig. 9b), considering the projected population growth for the next 20 years as suggested by Khan & Samadder (2015). As a result, areas less than 10 hectares were excluded, as indicated in Table 6. Figure 9b shows fifteen sites obtained from the WLC. Areas of the generated fifteen sites are given in Table 6. The results show that the 1st, 4th, 6th, 12th, and 13th sites encompass considerable areas of 2175, 157, 195, 2255 and 106 ha, respectively.

Potential landfills considering hydro-environmental conditions

Developing a sustainable MSWD suitability map requires prioritizing hydro-environmental factors to ensure effective waste management and protect public health and the environment. Understanding the hydro-geological setting, including aquifer depth and water body distribution, is crucial to avoid dumping SW into main water resources (Datta et al., 2024; Eleraki

et al., 2010). Initially, fifteen SW disposal sites were statistically compared with the LULC pattern using a bar diagram (Fig. 10). The AHP of the three layers—land use, settlement, and surface water bodies—was calculated (Fig. 3). Table 7 presents the PWCM. Table 8 explains the normalized matrix and rate of these three layers. Table 9 outlines the ranking of the fifteen landfill sites concerning their suitability for land use, distance from settlements, and water bodies. Final rankings for the fifteen identified sites were determined based on their suitability concerning land use, distance from settlements, and proximity to water bodies, using the AHP-produced rates. The analysis indicates that sites 4, 9, and 15 are distant from land use classes, whereas sites 10, 13, and 14 fall within these critical classes. Therefore, site 15 is ranked 1, site 9 is ranked 2, and site 4 is ranked 3. In contrast, sites 10, 13, and 14 are ranked 13, 14, and 15, respectively. Despite its proximity to site 6, the Amin Bazar area is 7 km from the city boundary. Sites 1, 4, and 12 are more securely distanced from settlement areas and are ranked 1, 3, and 2, respectively, while sites 2, 3, and 9 are closer to settlements and ranked 13, 14, and 15, respectively. Sites 1, 2, and 12 are suitably distanced from water bodies, earning rankings of 1, 3, and 2, respectively, whereas sites 4, 10, and 14 are less suitably located and ranked 13, 15, and 14, respectively.

Secondly, a 3D hydro-stratigraphic model was employed to examine soil discontinuities and groundwater conditions (Royse et al., 2009). The model shows a heterogeneous hydrological condition of different aquifers (Fig. 12a), and the soil units are interdigitated rather than interlayered. Moreover, the depth of GwT ranges from 13.6 to 20.3 m in the northern areas (Fig. 8a), as the clay thickness decreases between 1 and 5.43 m (Fig. 12d-e). These conditions can facilitate contaminants transportation, increasing the risk of groundwater pollution (Gemail et al., 2017; Khalil et al., 2022). This observation also aligns perfectly with the statistical findings, which revealed that northern sites, including 1st to 11th, have a significantly higher vulnerability to environmental risks. Moreover, the resulting MSWD_{OF} map is deemed to be validated against the existing landfill areas in the southeastern and southeastern parts (Figs. 1c and 11). Consequently, the 12th site (Zone A) and the 15th site (Zone B) were identified as relatively optimal future selections for waste disposal sites (Fig. 11). Zone B is

located close to the existing Matuail landfill area. The suitable Zones A and B sites cover 2255 and 30 ha, respectively.

In line with De Feo and De Gisi (2014), selecting suitable landfill sites becomes especially critical in developing countries due to weak environmental regulations, rapid urbanization, and scarcity of appropriate land. This study demonstrates the superior efficiency of integrating a 3D hydro-stratigraphic model with MSWD mapping compared to solely relying on information from a GIS-based AHP model for comprehensive site suitability assessment in complex megacity environments. The integration of land use analysis, statistical methods, and subsurface assessments has led to the identification of more suitable landfill sites compared to traditional models. This comprehensive approach significantly enhances decision-making for waste disposal, facilitating access to clean water (SDG 6). This study provides urban planners with existing and potential future waste disposal locations in Dhaka through the utilization of a remote sensing and GIS-AHP framework, coupled by land-use and hydro-environmental analyses. This structured approach bridges the gap between researchers and policymakers, facilitating the implementation of effective waste management practices that align with climate change mitigation policies (SDGs 11 and 13) in Bangladesh (Martin et al., 2013). By following this framework, Dhaka North and South city corporations and other stakeholders can make more informed decisions regarding future landfill site selection, thereby promoting sustainable waste management and environmental protection. Waste-to-energy projects can generate employment opportunities and minimize landfilled waste, promoting sustainable land management for agricultural activities, aligning with SDG 15 (Mohod & Bagal, 2023; Nasr, 2024). This highlights the importance of moving beyond single-method approaches and embracing comprehensive strategies for sustainable landfill development in challenging delta megacities.

Conclusions

Selecting suitable solid waste disposal sites in densely populated deltas of developing countries is challenging due to limited public awareness about waste management. To address this, a structured approach was

used to select MSWD sites in Dhaka, minimizing environmental risks. This study employs an AHP-integrated GIS approach to synthesize geomorphological, geological, socioeconomic, hydrogeological, and climatological factors, combined with land-use and hydro-environmental analyses, for mapping MSWD_{OF} sites. Eleven thematic layers, rated from 1 to 5 based on suitability, were weighted using PWCM to generate the MSWD map via the WLC method. The analysis revealed LULC, SL, DW, and DS significantly influenced SW disposal site suitability, while slope ST had the least impact. The MSWD map showed five suitability classes from very highly suitable (1) to unsuitable (5). Due to limited highly suitable areas (class 2), focus shifted to class 1 areas, identifying 15 potential MSWD_P sites, each over 10 ha. Integrating statistical land-use suitability analysis with AHP-based ratings for land use, distance to settlements, and water bodies produced an MSWD_{OF} map identifying two suitable waste disposal sites. The 3D hydro-stratigraphic model confirmed northern sites' unsuitability due to shallow groundwater (<5.43 m) and thin clay, excluding 11 options. Thus, sites 12 (Zone A, 2255 ha) and 15 (Zone B, 30 ha), with deeper groundwater tables and thicker clay layers, were identified as optimal for future waste disposal. To this end, this study significantly impacts sustainable waste disposal planning in Southeast Asian delta megacities, especially those experiencing rapid urbanization and rising sea levels. By offering crucial insights into the interplay between geospatial factors and site suitability, our comprehensive approach enables planners to make informed decisions that minimize environmental impact and transportation costs. The valuable application of GIS and remote sensing in analyzing land use patterns and subsurface conditions demonstrates the potential of these tools for large-scale waste management. Prioritizing the investigation of population growth patterns, extreme weather events, and economic considerations will enhance the accuracy of waste disposal modeling and ensure long-term sustainability for delta megacities.

Acknowledgements The authors would like to acknowledge the Deanship of Graduate Studies and Scientific Research, Taif University for funding this work. The authors debited to the anonyms reviewers for their constructive reviews that improved the manuscript considerably. The authors would also like to thank the USGS Earth Explorer for providing the Landsat and SRTM datasets.

Author contributions Arefin R. and Youssef YM conceived, designed and led the research and paper editing; ATMS Rahman, Abd El Aal A., Gomaa E., Radwan A., and Youssef YM supported the paper editing and the research conceptualization; Arefin R, Jahan CS, and Mazumder QH conducted the Field observations; Arefin R, Youssef YM, Das J, and ATMS Rahman were in charge of the analytical development and formal analysis of results. The Discussion and Conclusions sections were addressed by all authors, and all authors drafted the paper. All authors have read and agreed to the published version of the manuscript.

Funding This work is funded and supported by the Deanship of Graduate Studies and Scientific Research, Taif University.

Data Availability The datasets generated during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethical approval The manuscript is based on the research carried out by the co-authors. It is, therefore, an original research article which is not under consideration for publication elsewhere.

Conflict of interest The authors declare no conflict of interest.

References

Abdallah, M., Arab, M., Shabib, A., et al. (2020). Characterization and sustainable management strategies of municipal solid waste in Egypt. *Clean Technologies and Environmental Policy*, 22, 1371–1383. <https://doi.org/10.1007/s10098-020-01877-0>

Abdel-Shafy, H. I., & Mansour, M. S. M. (2018). Solid waste issue: Sources, composition, disposal, recycling, and valorization. *Egyptian Journal of Petroleum*, 27, 1275–1290. <https://doi.org/10.1016/j.ejpe.2018.07.003>

Abir, T., Ekwudu, O., Kalimullah, N. A., Nur-A Yazdani, D. M., Al Mamun, A., Basak, P., Osuagwu, U. L., Permarupan, P. Y., Milton, A. H., Talukder, S. H., & Agho, K. E. (2021). Dengue in Dhaka, Bangladesh: Hospital-based cross-sectional KAP assessment at Dhaka North and Dhaka South City Corporation area. *PLoS One*, 16(3), e0249135.

Abu El-Magd, S. A., Masoud, A. M., Hassan, H. S., Nguyen, N.-M., Pham, Q. B., Haneklaus, N. H., Hlawitschka, M. W., & Maged, A. (2024). Towards understanding climate change: impact of land use indices and drainage on land surface temperature for valley drainage and non-drainage areas. *Journal of Environmental Management*, 350, 119636. <https://doi.org/10.1016/j.jenvman.2023.119636>

Abu Salem, H. A., Gemail, Kh. S., & Nosair, A. (2021). A multidisciplinary approach for delineating wastewater flow paths in shallow groundwater aquifers: A case study

in the southeastern part of the Nile Delta, Egypt. *Journal of Contaminant Hydrology*. <https://doi.org/10.1016/j.jconhyd.2020.103701>

Ahmed, M. A., Saiek, Z. M., Chowdhury, O. R., Tamanna, M., & Tewari, S. (2018). Sustainable wastewater management for underdeveloped communities – a hands-on method for qualitative and quantitative analysis of greywater. *International Journal Environment and Sustainable Development*, 17(1), 93–109.

Ahmed, M. F., & Rahman, M. M. (2000). *Water supply & sanitation: Rural and low-income urban communities*. ITN-Bangladesh, Centre for Water Supply and Waste Management, BUET, Dhaka, Bangladesh with Contribution from IRC, International Water and Sanitation Center.

Akhtar, N., Syakir Ishak, M. I., Bhawani, S. A., & Umar, K. (2021). Various natural and anthropogenic factors responsible for water quality degradation: A review. *Water*, 13(19), 2660. <https://doi.org/10.3390/w13192660>

Akther, A., Ahamed, T., Noguchi, R., et al. (2019). Site suitability analysis of biogas digester plant for municipal waste using GIS and multi-criteria analysis. *Asia-Pacific Journal of Regional Science*, 3, 61–93. <https://doi.org/10.1007/s41685-018-0084-2>

Alam, M. K., Hasan, A. K. M., Khan, M. R., & Whitney, J. W. (1990). *Geological Map of Bangladesh*. Government of the People’s Republic of Bangladesh.

Alfy, Z. E., Elhadary, R., & Elashry, A. (2010). Integrating GIS and MCDM to deal with landfill site selection. *International Journal of Engineering & Technology*, 10, 32–41.

Ali, M., Wang, W., Chaudhry, N., & Geng, Y. (2017). Hospital waste management in developing countries: A mini-review. *Waste Management & Research*, 35, 581–592.

Aly, M. H., Giardino, J. R., & Klwin, A. G. (2005). Suitability assessment for new Minia city, Egypt, A GIS approach to engineering geology. *Environmental & Engineering Geoscience XI*, 3, 259–269.

Amin, M. A. (2021). *Matuail landfill emits 4 tonnes of methane every hour: ‘Unbelievable’ say experts*. The Business Standard (TBS): 29 April 2021. Retrieved May 30, 2024, from <https://www.tbsnews.net/environment/matuail-landfill-emits-4-tonnes-methane-every-hour-unbelievable-say-experts-238843>

APO. (2007). *Solid waste management: Issues and challenges in Asia*. Report of the APO Survey on Solid Waste Management 2004-05. Published by the Asia Productivity Organization 1-2-10 Hirakawacho Chiyodaku. <https://www.apo-tokyo.org/publications/solid-waste-management-issues-and-challenges-in-asia-pdf-2-2mb>

Arefin, R. (2020). Groundwater potential zone identification using an analytic hierarchy process in Dhaka City, Bangladesh. *Environmental Earth Sciences*, 79, 268. <https://doi.org/10.1007/s12665-020-09024-0>

Arefin, R., & Alam, J. (2020). Morphometric study for water resource management using principal component analysis in Dhaka City, Bangladesh: An RS and GIS approach. *Sustainable Water Resources Management*, 6, 38. <https://doi.org/10.1007/s40899-020-00402-x>

Bangladesh Water Development Board (BWDB). (1991). Project performance for Dhaka Integrated Flood Protection Project. Open file report. Bangladesh Water Development

- Board and Planning commission, Ministry of Planning, Government of Bangladesh.
- Beskese, A., Demir, H. H., Ozcan, H. K., & Okten, H. E. (2015). Landfill site selection using fuzzy AHP and fuzzy TOPSIS: A case study for Istanbul. *Environment and Earth Science*, 73(7), 3513–3521.
- Bilgilioglu, S., Gezgin, C., Orhan, O., et al. (2022). A GIS-based multi-criteria decision-making method for the selection of potential municipal solid waste disposal sites in Mersin, Turkey. *Environmental Science and Pollution Research*, 29, 5313–5329. <https://doi.org/10.1007/s11356-021-15859-2>
- Blight, G. E., & Mbande, C. M. (1996). Some problems of waste management in developing countries. *Journal of Solid Waste Technology and Management*, 23, 19–27.
- Cao, L. W., Cheng, Y. H., Zhang, J., Zhou, X. Z., & Lian, C. X. (2006). Application of grey situation decision-making theory in site selection of a waste sanitary landfill. *Journal of China University of Mining and Technology*, 16(4), 393–398. [https://doi.org/10.1016/S1006-1266\(07\)60033-9](https://doi.org/10.1016/S1006-1266(07)60033-9)
- Chavez, P. S., Jr. (1988). An improved dark object subtraction technique for atmospheric correction of multispectral data. *Remote Sensing of Environment*, 24(3), 459–479. [https://doi.org/10.1016/0034-4257\(88\)90019-3](https://doi.org/10.1016/0034-4257(88)90019-3)
- Chakraborty, M., Mukherjee, A., & Ahmed, K. M. (2021). Chapter 10 - Transboundary groundwater of the Ganges Brahmaputra–Meghna River delta system. In A. Mukherjee, B. R. Scanlon, A. Aureli, S. Langan, H. Guo, & A. A. McKenzie (Eds.), *Global Groundwater* (pp. 129–141). Elsevier. <https://doi.org/10.1016/B978-0-12-818172-0.00010-4>
- Chowdhury, T. A., & Afza, S. R. (2006). Waste management in Dhaka City-A theoretical marketing model. *BRAC University Journal III*, 2, 101–111.
- Datta, S., Mitra, M., & Roy, S. (2024). Sustainable Solid Waste Disposal to Mitigate Water Pollution Problem and Its Social Environmental Impact. In: Nasr, M., Ravindran, B. (eds) *Solid Waste Management in Delta Region for SDGs Fulfillment. Deltas of the World*. Springer, Cham. https://doi.org/10.1007/978-3-031-58253-0_3.
- De Feo, G., De Gisi, S. (2014). Using MCDA and GIS for hazardous waste landfill siting considering land scarcity for waste disposal. *Waste Management*, 34, 2225–2238.
- Demesouka O. E., Vavatsikos A. P., & Anagnostopoulos K. P. (2014). GIS-based multi-criteria municipal solid waste landfill suitability analysis: A review of the methodologies performed, and criteria implemented. *Waste Management & Research* 32(4), 270–296.
- Demographia. (2019) Demographia world urban areas. *Dhaka University Journal of Earth and Environmental Sciences*, 1(2), 83–89. <http://www.demographia.com/db-worldua.pdf>. Accessed 5 May 2024.
- Edmonds, D. A., Caldwell, R. L., Brondizio, E. S., et al. (2020). Coastal flooding will disproportionately impact people on river deltas. *Nature Communications*, 11, 4741.
- El-Aal, A. A., Radwan, A. E., Abdelshafy, M., et al. (2024). A synergistic use of remote sensing and hydrodynamic techniques for flash flood mitigation toward sustainable urban expansion in Najran Valley, Saudi Arabia. *Earth Systems and Environment*, 8, 465–482. <https://doi.org/10.1007/s41748-024-00371-7>
- Eleraki, M., Gadallah, M. M., Gemail, K. S., & Attwa, M. (2010). Application of resistivity method in environmental study of the appearance of soil water in the central part of Tenth of Ramadan City, Egypt. *Quarterly Journal of Engineering Geology and Hydrogeology*, 43(2), 171–184. <https://doi.org/10.1144/1470-9236/08-079>
- Elmahdy, S. I., & Mohamed, M. M. (2016). Land use/land cover change impact on groundwater quantity and quality: A case study of Ajman Emirate, the United Arab Emirates, using remote sensing and GIS Arabian. *Journal of Geosciences*, 9, 722.
- Embaby, A., Youssef, Y. M., & Abu El-Magd, S. A. (2024). Delineation of lineaments for groundwater prospecting in hard rocks: Inferences from remote sensing and geophysical data. *Environmental Earth Sciences* 83, 62. <https://doi.org/10.1007/s12665-023-11389-x>
- Fahmi, W., & Sutton, K. (2010). Cairo's Contested Garbage: Sustainable Solid Waste Management and the Zabaleen's Right to the City. *Sustainability*, 2(6), 1765–1783. <https://doi.org/10.3390/su2061765>
- Gemail, Kh., El Alfy, M., Ghoneim, M. F., Shishtawy, A. M., & Abd El-Bary, M. (2017). Comparison of DRAS-TIC and DC resistivity modelling for assessing aquifer vulnerability in the central Nile Delta, Egypt. *Environmental Earth Sciences*, 76, 350. <https://doi.org/10.1007/s12665-017-6688-4>
- Gemitzi, A., Tsihrintzis, V. A., Voudrias, E., Petalas, C., & Stravodimos, G. (2007). Combining geographic information system, multi-criteria evaluation techniques and fuzzy logic in siting MSW landfills. *Environmental Geology*, 51(5), 797–811. <https://doi.org/10.1007/s00254-006-0359-1>
- Gintamo, T. T. (2015). Groundwater potential evaluation based on integrated GIS and RS techniques in Bilate river catchment, South Rift Valley of Ethiopia. *American Scientific Research Journal for Engineering, Technology, and Sciences (ASRJETS)*, 10, 85–120.
- Guerrero, L. A., Maas, G., & Hogland, W. (2013). Solid waste management challenges for cities in developing countries. *Waste Management*, 33, 220–232. <https://doi.org/10.1016/j.wasman.2012.09.008>
- Halvadakis, C. P. (1993). Municipal solid waste landfill siting in Greece—the case of the greater hania region, Greece. *Ekistics*, 358–359, 45–52.
- Hasan, M. R., Tetsuo, K., & Islam, S. A. (2009). Landfill demand and allocation for municipal solid waste disposal in Dhaka city—an assessment in a GIS environment. *Journal of Civil Engineering*, 37, 133–149.
- Hasan, M.K., Burgess, W., Dottridge, J. (1999). The vulnerability of the Dupi Tila aquifer of Dhaka, Bangladesh. Impacts of Urban Growth on Surface Water and Groundwater Quality (Proceedings of IUGG 99 Symposium HS5, Birmingham, July. IAHS Publ. no. 259.
- Hoornweg, D., & Bhada-Tata, P. (2012). What a waste: A global review of solid waste management. *Urban Development Series Knowledge Papers*, 15, 1–98.
- Ibrahim-Bathis, K., & Ahmed, S. A. (2016). Geospatial technology for delineating groundwater potential zones in Doddahalla watershed of Chitradurga district, India. *The Egyptian Journal of Remote Sensing and Space Sciences*, 19(2), 223–234. <https://doi.org/10.1016/j.ejrs.2016.06.002>

- Islam, F. A. S. (2016). Solid Waste Management System in Dhaka City of Bangladesh. *Journal of Modern Science and Technology*, 4(1), 192–209.
- Islam, S. M. D., Rahman, S. H., Hassam, M., & Azam, G. (2016). Municipal Solid Waste Management using GIS Application in Mirpur Area of Dhaka City, Bangladesh. *Pollution*, 2, 141–151. <https://doi.org/10.7508/pj.2016.02.004>
- Iyer, H. (2016). Case Study of Mumbai: Decentralised Solid Waste Management. *Procedia Environmental Sciences.*, 35, 101–109.
- Kamal. A. M., & Midorikawa, S. (2006). Geomorphological approach for seismic microzoning within Dhaka city area, Bangladesh. *International Journal of Applied Earth Observation and Geoinformation*, 6, 111–125. <https://api.semanticscholar.org/CorpusID:131486716>. Accessed 15 Jan 2024.
- Kaza, S., Yao, L. C., Bhada-Tata, P., & Van Woerden, F. (2018). What a waste 2.0: A global snapshot of solid waste management to 2050. Urban Development, World Bank. <http://hdl.handle.net/10986/30317>
- Khalil, M. M. E., Khodary, S. M., Youssef, Y. M., Alsubaie, M. S., & Sallam, A. (2022). Geo-environmental hazard assessment of archaeological sites and archaeological domes—Fatimid tombs—Aswan, Egypt. *Buildings*, 12, 2175. <https://doi.org/10.3390/buildings12122175>
- Khan, D., & Samadder, S. R. (2015). A simplified multi-criteria evaluation model for landfill site ranking and selection based on AHP and GIS. *Journal of Environmental Engineering and Landscape Management*. <https://doi.org/10.3846/16486897.2015.1056741>
- Lim, S. L., Lee, L. H., & Wu, T. Y. (2016). Sustainability of using composting and vermicomposting technologies for organic solid waste biotransformation: Recent overview, greenhouse gases emissions and economic analysis. *Journal of Cleaner Production*, 111, 262–278.
- Lin, H. Y., & Kao, J. J. (1998). A vector-based spatial model for landfill siting. *Journal of Hazardous Materials*, 58(1), 3–14. [https://doi.org/10.1016/S0304-3894\(97\)00116-7](https://doi.org/10.1016/S0304-3894(97)00116-7)
- Maitra, M. K., & Akhter, S. H. (2011). Neotectonics in Madhupur tract and its surrounding floodplains. *Dhaka University Journal of Earth and Environmental Sciences*, 1(2), 83–89.
- Malczewski, J. (1997). Propagation of errors in multicriteria location analysis: A case study. In G. Fandel & T. Gal (Eds.), *Multiple criteria decision making* (pp. 154–155). Springer.
- Mallick, J. (2021). Municipal Solid waste landfill site selection based on fuzzy-AHP and geoinformation techniques in Asir Region Saudi Arabia. *Sustainability*, 13(3), 1538. <https://doi.org/10.3390/su13031538>
- Martin, M., Kang, Y. H., Billah, M., Siddiqui, T., Black, R., & Kniveton, D. (2013). *Policy analysis: Climate change and migration Bangladesh*. Refugee and Migratory Movements Research Unit (RMMRU). <http://www.migratingo.utfopoverty.org/documents/wp4-ccrm-b-policy.pdf>
- Mekuria, T. (2006). A multi-criteria analysis for solid waste disposal site selection using Remote Sensing and GIS, Addis Ababa University, Ethiopia. Unpublished master's Thesis, 11–25.
- Moeinaddini, M., Khorasani, N., Danehkar, A., & Darvishsefat, A. A. (2010). Siting MSW landfill using weighted linear combination and analytical hierarchy process (AHP) methodology in GIS environment (case study: Karaj). *Waste Management*, 30(5), 912–920. <https://doi.org/10.1016/j.wasman.2010.01.015>
- Mohod, M., & Bagal. (2023). Technological developments in the energy generation from municipal solid waste (landfill gas capture, combustion, pyrolysis and gasification). 360-Degree Waste Management, Volume 1: Fundamentals, Agricultural and Domestic Waste, and Remediation, pp. 139–157. <https://doi.org/10.1016/B978-0-323-90760-6.00005-9>
- Mussa, A., & Suryabhadgavan, K. V. (2019). Solid waste dumping site selection using GIS-based multi-criteria spatial modelling: A case study in Logia town. *Afar Region, Ethiopia, Geology, Ecology, and Landscapes*. <https://doi.org/10.1080/24749508.2019.1703311>
- Nasr, M. (2024). Solid Waste Management and Sustainability in Deltas: Concluding Remarks and Outlook. In: Nasr, M., Ravindran, B. (eds) *Solid Waste Management in Delta Region for SDGs Fulfillment*. Deltas of the World. Springer, Cham. https://doi.org/10.1007/978-3-031-58253-0_10
- Paul, S., & Ghosh, S. (2022). Identification of solid waste dumping site suitability of Kolkata Metropolitan Area using Fuzzy-AHP model. *Cleaner Logistics and Supply Chain*, 3, 100030.
- Paul, K., Dutta, A., & Krishna, A. P. (2014). A comprehensive study on landfill site selection for Kolkata City, India. *Journal of the Air & Waste Management Association*, 64(7), 846–861. <https://doi.org/10.1080/10962247.2014.896834>
- Pekkan, E., Tun, M., Guney, Y., & Mutlu, S. (2015). Integrated seismic risk analysis using simple weighting method: The case of residential Eskişehir, Turkey. *Natural Hazards and Earth System Sciences*, 15, 1123–1133.
- Rahman, S.M.S., Kashif, S.S.M. (2009). Study of Solid Waste Management and its Impact on Climate Change: A Case Study of Dhaka City in Bangladesh. Bangladesh Environment Network JAPAN.
- Rahman, M.M., Ghosh, T., Salehin, M., Ghosh, A., Haque, A., Hossain, M.A., Das, S., Hazra, S., et al. (2020). Ganges-Brahmaputra-Meghna Delta, Bangladesh and India: A Trans-national Mega-Delta. In: Nicholls, R., Adger, W., Hutton, C., Hanson, S. (eds) *Deltas in the Anthropocene*. Palgrave Macmillan, Cham. https://doi.org/10.1007/978-3-030-23517-8_2
- Rahmat, Z. G., Niri, M. V., Alavi, N., Goudarzi, G., Babaei, A. A., Baboli, Z., & Hosseinzadeh, M. (2016). Landfill site selection using GIS and AHP: A case study: Behbahan, Iran. *KSCCE Journal of Civil Engineering*, 21(1), 111–118. <https://doi.org/10.1007/s12205-016-0296-9>
- Razia, S., & Bakar Ah, S. H. A. (2023). Model of social sustainability for Dhaka city, Bangladesh. *Humanities and Social Sciences Communications*, 10, 680. <https://doi.org/10.1057/s41599-023-02144-5>
- Royse, K. R., Rutter, H. K., & Entwisle, D. C. (2009). Property attribution of 3D geological models in the Thames Gateway, London: New ways of visualizing geoscientific information. *Bulletin of Engineering Geology and the Environment*, 68(1), 1–16.
- Saaty, T. L. (1977). A scaling method for priorities in hierarchical structures. *Journal of Mathematical Psychology*, 15(3), 234–281. [https://doi.org/10.1016/0022-2496\(77\)90033-5](https://doi.org/10.1016/0022-2496(77)90033-5)
- Saaty, T. L. (1980). *The Analytic Hierarchy Process* (p. 278). McGraw-Hill.
- Salam, A. (2000). Analysis and design of solid waste management system for a residential zone of Dhaka city. M. Sc. Thesis, Department of Civil Engineering, BUET.

- Sam, Z., & Steven, J. (2017). Site suitability analysis for solid waste landfill site location using geographic information systems and remote sensing: A case study of Banket town board, Zimbabwe. *Review of Social Sciences*, 2, 19–31.
- Santhosh, L. G., & Babu, G. L. S. (2018). Landfill site selection based on reliability concepts using the DRASTIC method and AHP integrated with GIS – a case study of Bengaluru city, India. *Georisk: Assessment and Management of Risk for Engineered Systems and Geohazards*, 12(3), 234–252. <https://doi.org/10.1080/17499518.2018.1434548>
- Şener, Ş., Şener, E., Nas, B., & Karagüzel, R. (2010). Combining AHP with GIS for landfill site selection: A case study in the Lake Beyşehir catchment area (Konya, Turkey). *Waste Management*, 30(11), 2037–2046. <https://doi.org/10.1016/j.wasman.2010.05.024>
- Shah, B. (2021). Sustainable landfill site selection for construction and demolition waste management using GIS and AHP. *Advances in Energy and Environment* (pp. 135–142). Springer.
- Simion, I. M., Ghinea, C., Maxineasa, S. G., Taranu, N., Bonoli, A., & Gavrilesco, M. (2013). Ecological footprint applied in the assessment of construction and demolition waste integrated management. *Environmental Engineering and Management Journal*, 12(4), 779–788.
- Soudani, L. et al. (2024). Integrated Waste Management System for Environment Protection in Deltas. In: Nasr, M., Ravindran, B. (eds) Solid Waste Management in Delta Region for SDGs Fulfillment. Deltas of the World. Springer, Cham. https://doi.org/10.1007/978-3-031-58253-0_4
- Streatfield, P. K., & Karar, Z. A. (2008). Population challenges for Bangladesh in the coming decades. *Journal of Health, Population and Nutrition*, 26. <https://doi.org/10.3329/jhpn.v26i3.1894>
- Tania, F. (2014). Solid Waste Management of Dhaka City: A Socio-economic analysis. *Banglavisian*, 13(1), 92–100.
- Tercan, E., Dereli, M. A., & Tapkın, S. (2020). A GIS-based multi-criteria evaluation for MSW landfill site selection in Antalya, Burdur, and Isparta planning zone in Turkey. *Environment and Earth Science*, 79, 1–17. <https://doi.org/10.1007/s12665-020-08974-9>
- Toha, M., & Rahman, M. M. (2023). Estimation and prediction of methane gas generation from landfill sites in Dhaka city, Bangladesh. *Case Studies in Chemical and Environmental Engineering*, 7(2), 100302, ISSN 2666–0164. <https://doi.org/10.1016/j.cscee.2023.100302>.
- Tortajada, C. (2008). Challenges and realities of water management of megacities: The case of Mexico City metropolitan area. *Journal of International Affairs*, 61(2), 147–166.
- United Nations. (2018). Sustainable Development Goal 6: Synthesis Report 2018 on Water and Sanitation. New York, USA. <https://www.unwater.org/publications/sdg-6-synthesis-report-2018-on-water-and-sanitation/>. (Accessed 1 January 2024). accessed.
- United Nations, Department of Economic and Social Affairs, Population Division (UNDESA/PD). (2019). World Urbanization Prospects 2018: Highlights (ST/ESA/SER.A/421).
- Van den Brandeler, F., Gupta, J., & Hordijk, M. (2019). Megacities and rivers: Scalar mismatches between urban water management and river basin management. *Journal of Hydrology*, 573, 1067–1074. <https://doi.org/10.1016/j.jhydrol.2018.01.001>
- Waste Concern. (2014). Bangladesh Waste Database 2014. Waste Concern Technical Report Series. Dhaka, Bangladesh. Retrieved from <http://wasteconcern.org/wp-content/uploads/2016/05/Waste-Data-Base_2014_Draft-Final.pdf> (accessed on 5 June 2024).
- Wilson, D.C. (2010). Comparative Analysis of Solid Waste Management. In Cities around the World. Paper Delivered at the UK Solid Waste Association.
- Xu, Z., Xu, J., Yin, H., Jin, W., Li, H., & He, Z. (2019). Urban river pollution control in developing countries. *Nature Sustainability*, 2, 158–160. <https://doi.org/10.1038/s41893-019-0249-7>
- Yesilnacar, M. I., Suzen, M. L., Kaya, B. S., & Doyuran, V. (2012). Municipal solid waste landfill site selection for the city of Sanliurfa-Turkey: an example using MCDA integrated with GIS. *International Journal of Digital Earth*, 5(2), 147–164.
- Yin, H., Islam, M. S., & Ju, M. (2021). Urban River Pollution in the Densely Populated City of Dhaka, Bangladesh: Big picture and rehabilitation experience from other developing countries. *Journal of Cleaner Production*, 321, Article ID: 129040.
- Youssef, Y., Gemail, K., Atia, H., & Mahdy, M. (2024). Insight into land cover dynamics and water challenges under anthropogenic and climatic changes in the eastern Nile Delta: Inference from remote sensing and GIS data. *Science of the Total Environment*, 913, 169690. <https://doi.org/10.1016/j.scitotenv.2023.169690>
- Youssef, Y. M., Gemail, K. S., Sugita, M., AlBarqawy, M., Teama, M. A., Koch, M., & Saada, S. A. (2021). Natural and Anthropogenic Coastal Environmental Hazards: An Integrated Remote Sensing, GIS, and Geophysical-based Approach. *Surveys in Geophysics*, 42, 1109–1141. <https://doi.org/10.1007/s10712-021-09660-6>
- Yousuf, T. B. (1996). Sustainability of solid waste management system of Dhaka City Corporation. M. Sc. Thesis, Department of Civil Engineering, BUET, Dhaka.
- Zahur, M. (2007). Solid waste management of Dhaka City: Public private community partnership. *BRAC University Journal IV*, 2, 93–97.

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Springer Nature or its licensor (e.g. a society or other partner) holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.