Environmental Earth Sciences (2020) 79:227
https://doi.org/10.1007/s12665-020-08970-z

ORIGINAL ARTICLE

Suitability analysis for municipal landfill site selection using fuzzy analytic hierarchy process and geospatial technique

Sk Ajim Ali[1] · **Ateeque Ahmad**[1]

Received: 25 July 2019 / Accepted: 27 April 2020 / Published online: 13 May 2020

Abstract
One of the most important challenges in solid waste management throughout the world is selection of suitable landfill sites. It is essential for solid waste management, because unscientific dumping and landfilling of waste could negatively impact the environment and human health. This research presents a GIS-based multi-criteria decision support approach for assessing the suitability analysis for landfill site selection in Kolkata Municipal Corporation, India. In highly urbanized areas of Kolkata, there is stress regarding the location of potential landfill sites, because existing waste dumping ground, i.e., Dhapa have no longer space to hold waste after 2 or 3 years. The availability of land is also a major tension than financial assistance in the study area. Therefore, the present study developed a methodological framework for locating suitable landfill candidate sites and selecting the best alternatives. Thus, 20 relevant alternatives were selected and relative weight calculated using the fuzzy analytic hierarchy process. The geographic information system was considered to arrange the spatial and aspatial data. The alternatives of all criteria were rated from 1–5 scale indicating lowest to highest suitability for landfill. The weighted linear combination was performed between different criteria for modeling suitable candidate sites. The results revealed that throughout the study area, initially, 16 candidate sites were identified based on geospatial analysis, but out of them, 13 sites cannot be accepted for a landfill site due to current land use, public acceptance, transportation, and local environmental issues. Only three suitable sites can be considered for landfilling, although these are also not completely satisfying the environmental concern. However, landfill site is also essential; otherwise, it will appear as more adverse impact. Therefore, with little compromising with the environmental component, the engineered plan can be designed for the sanitary landfill on specific sites that recommended in this suitability analysis.

Keywords Fuzzy analytic hierarchy process · Geographic information system · Municipal landfill site selection · Suitability analysis

Introduction

Solid waste is the refuse and unwanted solid materials which produced from the household, street sweeping, commercial, industrial, and agricultural operations of a particular area (Yang et al. 2013; Ali 2016). Municipal solid waste may be categorized according to its source, i.e., domestic, commercial, industrial, and constructional or institutional, and according to its contents, i.e., plastic, glass, metals, paper, and other organic materials (Cui and Zhang 2008; Pathak et al. 2009; Troschinetz and Mihelcic 2009; Long et al. 2011). Proper and sound management of solid waste is required, because it reduces the hazardous impacts on the environment and human health. However, the management of municipal solid waste (MSW) is becoming a major concern that facing by municipal authorities, city planners, and decision-makers due to limited resources, increasing population, rapid urbanization, and industrialization (Hazra and Goel 2009). The problems are more serious in developing countries where the unscientific method of solid waste management is practicing due to population growth, urbanization, and the poor state of human awareness (Hasan 2004; Gorsevski et al. 2012). This rapid growth of population and urbanization is not only responsible for generating a huge quantity of solid waste but also contribute to inappropriate dumping of such waste which is now key environmental

✉ Sk Ajim Ali
skajimali.saa@gmail.com; skajimali@myamu.ac.in

[1] Department of Geography, Faculty of Science, Aligarh Muslim University, Aligarh, Uttar Pradesh 202002, India

challenges faced by humans (Rahman et al. 2008; Gbanie et al. 2013).

Solid waste management involves the generation, collection, transport, and disposal. Solid waste disposal methods include open dumping, sanitary landfill, composting, incineration, grinding and discharging to sewer, compaction, hog feeding, milling, reduction, and anaerobic digestion (Mojiri et al. 2014). Disposal of waste plays a vital role in both environmental consequences and public health (Porta et al. 2009). Unscientific and improper methods of waste disposal have a negative impact on groundwater, surface water, air, and soil which also affect public health (Moghaddas and Namaghi 2009). There are different techniques available for waste management like reduce, reuse, recycle, composting, energy recovery, and landfill or disposal. Landfill or disposal of waste is considered as the worst method or bottom of waste management hierarchy which increases environmental impact (Mahini and Gholamalifard 2006; Rahman et al. 2008; Gbanie et al. 2013). Improper landfilling always has concerns about potential health effects. Several kinds of literature evidenced about potential health impacts on residents living nearer to landfill sites and incinerators (Rushton 2003; Minichilli et al. 2005). Any activities related with landfilling or dumping ground have been connected with reproductive problems and other dangerous outcomes like congenital malformations, low birth weight, multiple births, abnormal sex ratio of newborn, respiratory diseases, skin infection, gastrointestinal symptoms, and even cancer (Upton 1989; Knox 2000; Vrijheid 2000; Minichilli et al. 2006; Russi et al. 2008).

The existing situations of waste management are the same in all developing countries, with common characteristics of high waste generation, inappropriate collection and transfer, open dumping, burning, and poor landfilling (Troschinetz and Mihelcic 2009; Guerrero et al. 2013). India as a developing country, the same issues and problems are challenges environmental consequences. Most of the metropolitan cities of India like Mumbai, Delhi, Kolkata, and Chennai generate a gigantic quantity of waste daily but no proper management like sanitary landfill available (Dhokhikah and Trihadiningrum 2012). The final solid waste treatment and disposal in developing countries are commonly found as open dumping, landfill, and another method like incinerator and composting. Therefore, recently as a common method of waste management, special concern was given on landfill in the study. In the Indian context, landfill a site where mixed types of waste from diversified sources are dumped without segregation. Therefore, it is a quite difficult task to select proper and suitable sites for waste landfill, because the selection of landfill is driven by issues like availability of suitable lands, state and regional regulations, public awareness, environmental and health consequences, etc. (Kontos et al. 2005; Chiueh et al. 2008).

Traditionally, numerous practices and techniques for landfill siting can be found in the literature (Lukasheh et al. 2001). A number of GIS-based techniques have also been proposed for suitable landfill site selection (Kontos et al. 2003; Chiueh et al. 2008; Zamorano et al. 2008). Other landfill siting techniques combines multi-criteria decision-making approach with GIS (Chang et al. 2008; Onut and Soner 2008; Şener et al. 2010a, b; Tavares et al. 2011; Gorsevski et al. 2012; Beskese et al. 2015; Eskandari et al. 2016; Chabuk et al. 2017). These different techniques were used by different experts for selecting suitable landfill sites. Recently, the fuzzy set has been widely used combined with MCDM (multi-criteria decision-making) method to deal with vagueness in the landfill location selection process (Beskese et al. 2015; Hanine et al. 2016). Thus, fuzzy MCDM method, i.e., fuzzy analytic hierarchy process (FAHP), was used in the present study to suitability analysis of municipal waste landfill site selection, because it offers an appropriate language to manage inaccurate criteria by analyzing qualitative and quantitative factors.

With covering 205.05 Km^2 areas, Kolkata Municipal Corporation (KMC) has only about 35 ha (0.35 Km^2) area for disposing of the whole generated municipal solid waste. In a whole estimation, currently, the city has been generating about 4500 MT municipal solid waste daily. This generated waste is entirely disposed at Dhapa dumping area. Structurally, Dhapa dumping area is divided into two parts: one is closed dump and another is active dump area which is separated by a private composting plant. Out of total 35 ha areas, 12.14 ha area consists of the closed dump which was commenced operation during 1987 and was closed in 2009 and rest about 23 ha areas consists of active dumping area which was also commenced operations at the same time and its capacity to hold waste is near to over. More 10 ha area was extended to the western site of active dumping area and is expected for dumping waste for another 2 or 3 years.

On the other hand, with growing population and changing human lifestyle, there are different types and enormous quantities of waste generation. The data revealed that presently total 4500 MT/day waste is generated in the city which was 3600 MT/day during 2010. Out of total solid waste generation in the city, household sector or residential area highly contributed about 60% (2700 MT/day) of total waste generation. The second most waste generating sector is commercial refuse by contributing about 16% (700 MT/day). Along with street sweeping, constructional site, institutional refuse, and industrial area also share 11% (500 MT/day), 5% (230 MT/day), 4% (200 MT/day), and 4% (200 MT/day), respectively, in generating waste. Based on polluting material contains, solid waste may be categorized in various types. Pollution material includes chemicals, sewage, metals, pesticides, glass, damaged constructional materials, etc. Mixed organic type of waste, constructional waste, paper, and thin polythene carry bag share major position with average quantity of 15%, 10%, 7%, and 5%, respectively (Ali 2016). Hence, looking towards the quantity of waste generation and scarcity of disposing lands, it is a matter of concern to find a suitable place for the municipal landfill sites by taking environmental and health issues into consideration.

Therefore, the present study emphasized the application of GIS-based multi-criteria decision support system for selecting suitable municipal landfill site. The main aim of this study was to use spatial data, quantitative analysis, and propose landfill site by considering sensible factors. This study initially selected many suitable sites based on geo-spatial analysis but finally considered only a few by keeping in mind the scarcity of land issues within the city and community acceptance.

GIS and suitability analysis

The geographic information system has been used for the operation and representation of geospatial data in suitability analysis during the last few years (Vahidnia et al. 2009). GIS has the special efficiency to determine the appropriateness of a given place for a particular application. The main goal of suitability analysis is to find the degree of either suitable or unsuitable for specific cases. GIS-based suitability analysis depends on a systematic and multi-factor analysis of a different aspect of problems. Thus, the integration of multi-criteria and GIS has gained significant interest in researchers over time (Malczewski 2006). With growing such interest in applying GIS and multi-criteria decision analysis, it helps the decision-makers to understand practical problems (Chen et al. 2010). Recently, suitability mapping techniques and GIS have been widely used in problems to best location selection and spatial decision support.

Suitability analysis for determining landfill sites is an extremely difficult task, because the selection process typically requires spatial data with respect to various siting rules, regulations, factors, and constraints. However, due to appropriate result in site selection process, its application becomes popularity and gained the great field of interest (Kao and Lin 1996; Kontos et al. 2005; Delgado et al. 2008; Sharifi et al. 2009; Nas et al. 2010; Donevska et al. 2011; Gorsevski et al. 2012; Demesouka et al. 2013; Khorram et al. 2015; Chabuk et al. 2017). In this regard, several tools and techniques are available to define optimum site which is categorized into the expert system (EX) where problems are well structured and decision support system (DSS) where problems are ill-structured (Witlox 2005; Vahidnia et al. 2009). Multi-criteria as a decision support system while combined with GIS can facilitate optimum site selection to decision-maker (Zucca et al. 2008; Chang et al. 2008). Different methods of multi-criteria decision support system recently used for GIS-based site selection and effective map layer; for example, analytical hierarchy process and ordered weighted average (Gorsevski et al. 2012; Jaybhaye et al. 2014; Chabuk et al. 2017; Guler and Yomralıoglu 2017), Fuzzy MCDM (Chang et al. 2008; Alves et al. 2009; Kharat et al. 2016), Fuzzy AHP and fuzzy TODIM (Hanine et al. 2016; Torabi-Kaveh et al. 2016), and fuzzy TOPSIS (Onut and Soner 2008; Beskese et al. 2015).

The present study designed a multi-factor decision support system with a few defined alternatives that directly related to the suitability analysis of landfill site selection. Choosing of maximum associated criteria will minimize the effort to solve defined problems. Thus, the main objective of this study was to prepare an analytical structure with spatial data sets using interpolation, proximity, and spatial inquiry. Fuzzy multi-criteria tool was then used to prioritize selected data sets and select suitable sites with spatial consideration. The following figure presents the detailed methodology applied to suitability analysis for municipal landfill site selection (Fig. 1).

Application case (description of study area)

The application case to select suitable landfill sites is Kolkata Municipal Corporation (KMC) which is the largest urban agglomeration and municipal corporation of West Bengal state, India. With 44,96,694 residential populations, 10,24,928 households and about 60,00,000 floating population per day, KMC is India's third largest metropolitan city as well as the world's eighth largest urban agglomeration. Geographically, KMC is located in 45 N UTM zone with 22° 28′ 00″ N to 22° 37′ 30″ N and 88° 14′ 30″ E to 88° 25′ 30″ E (Fig. 2). KMC has 144 administrative wards which are divided into 16 Boroughs with covering an area of 205.07 Km^2. Many portions of the city were once part of wetlands that reclaimed over the time to house the growing population. The average elevation of the city lies between 1.5 m and 16 m above MSL. Kolkata receives an average temperature of 26.8° C or 80.24° F, but the temperature exceeds above 40° C during May–June. The city also receives an averagely 1600 mm rainfall with the highest rainfall during August.

Not only the residential populations but also a huge amount of daily floating populations generate an enormous quantity of municipal solid waste (MSW) throughout the city. The urban local bodies (ULBs) tried to do their best to handle the growing magnitude of problems relating to solid waste management (Chattopadhyay et al. 2009). It is projected that during 2035, the city will generate a quantity of 8805 MT/day MSW (Ali 2016). The major problems that the authority faces regarding solid waste management are the lack of places for waste disposal. The city has now only about 33 ha areas for disposing of municipal solid waste

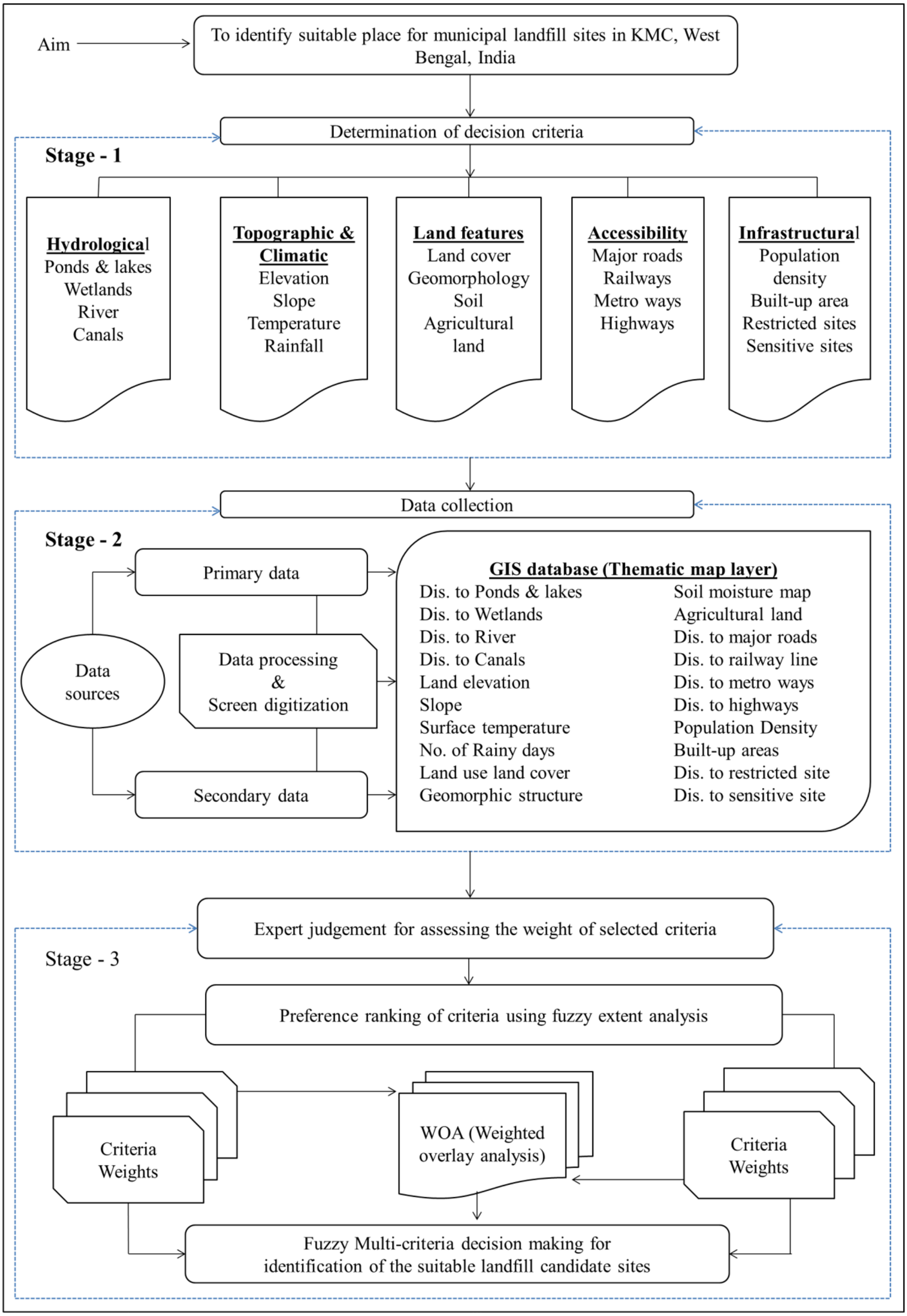

Fig. 1 Flow chart of methodology applied to suitability analysis for municipal landfill site selection

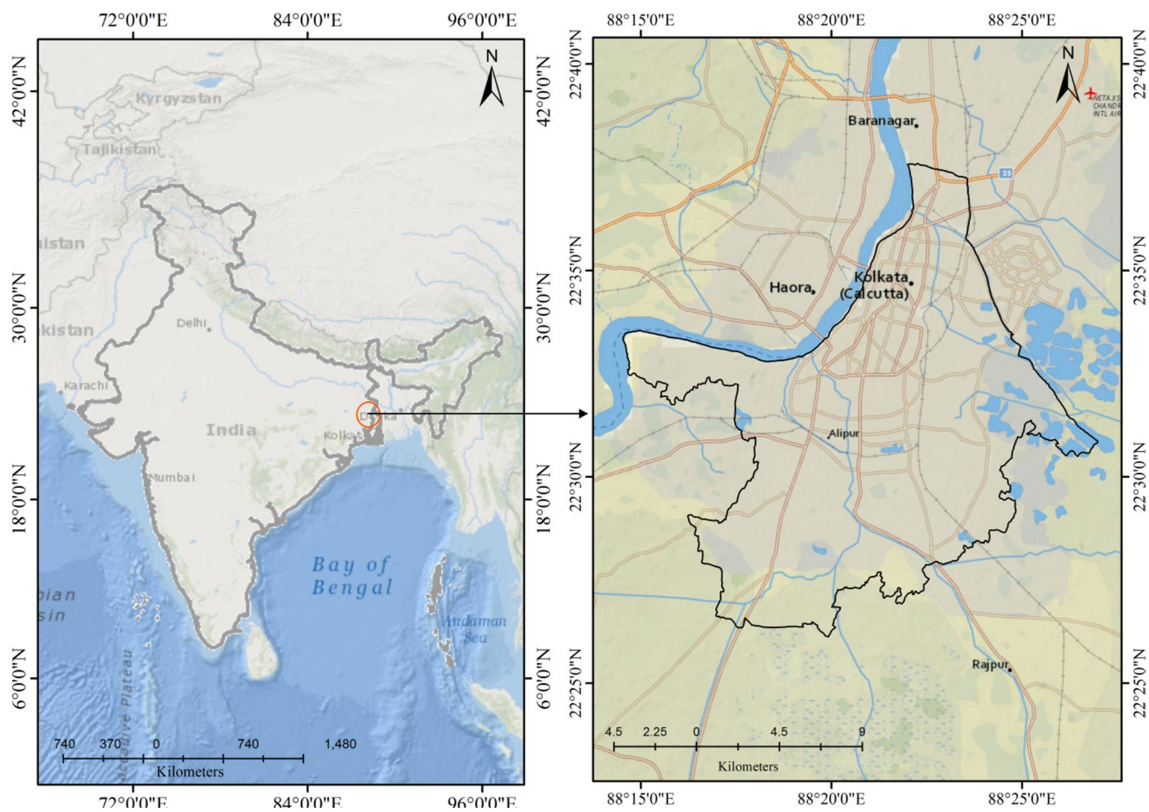

Fig. 2 Geographical location of case study area

and many issues are raised due to the unavailability of land. Therefore, it is immediately required to identify a suitable place for locating new landfill sites.

Materials and methods

Data collection

The data sets were spatial in nature, as the present study emphasized on spatial suitability analysis for landfill site selection. Datasets like satellite images, digital elevation model (DEM), hydrological data, climatic data, GPS coordinates, and data on accessibility and infrastructure, etc. were collected from different sources. Satellite data like Landsat 8 (OLI and TIRS) were collected from USGS earth explorer portal (https://earthexplorer.usgs.gov) and particular bands were taken for using purpose, Sentinel-L2A data were collected from Sentinel Hub EO browser (https://www.sentinel-hub.com/explore/eobrowser), and specific bands were utilized for study purpose. DEM file was retrieved from earth data, NASA web portal (https://earthdata.nasa.gov/). Along with these satellite data, hydrological, climatic, land features, and other spatial data were collected from different sources like a weather report, meteorological station Kolkata, district statistical handbook-Kolkata, Google Earth Pro, and field-based GPS location (Fig. 3). These all selected data sets were then processed for using purpose by converting and reclassifying into the same projection system and equal cell size.

Criteria selection for suitable landfill site

The selection of appropriate criteria is the main task for any kind of suitability analysis. The criteria selection differs with study objectives and geographical locations. As far as the present study is concerned, multiple criteria should require to consider, because landfill is a practice where the disposal of waste materials takes place and the surrounding environmental components and public health are truly impacted due to unscientific disposal and management. Criteria for suitability analysis of landfill site selection at global scales have differed in the previous studies (Table 1).

Through the detailed literature survey and guidelines of pollution control board on landfill site selection, 20 relevant and site-specific criteria were selected in the present study to identify the suitable site of a landfill in Kolkata Municipal Corporation (KMC), India. To normalize and reduce the calculation complexity, these 20 criteria were combined into five categories by putting four criteria in each category.

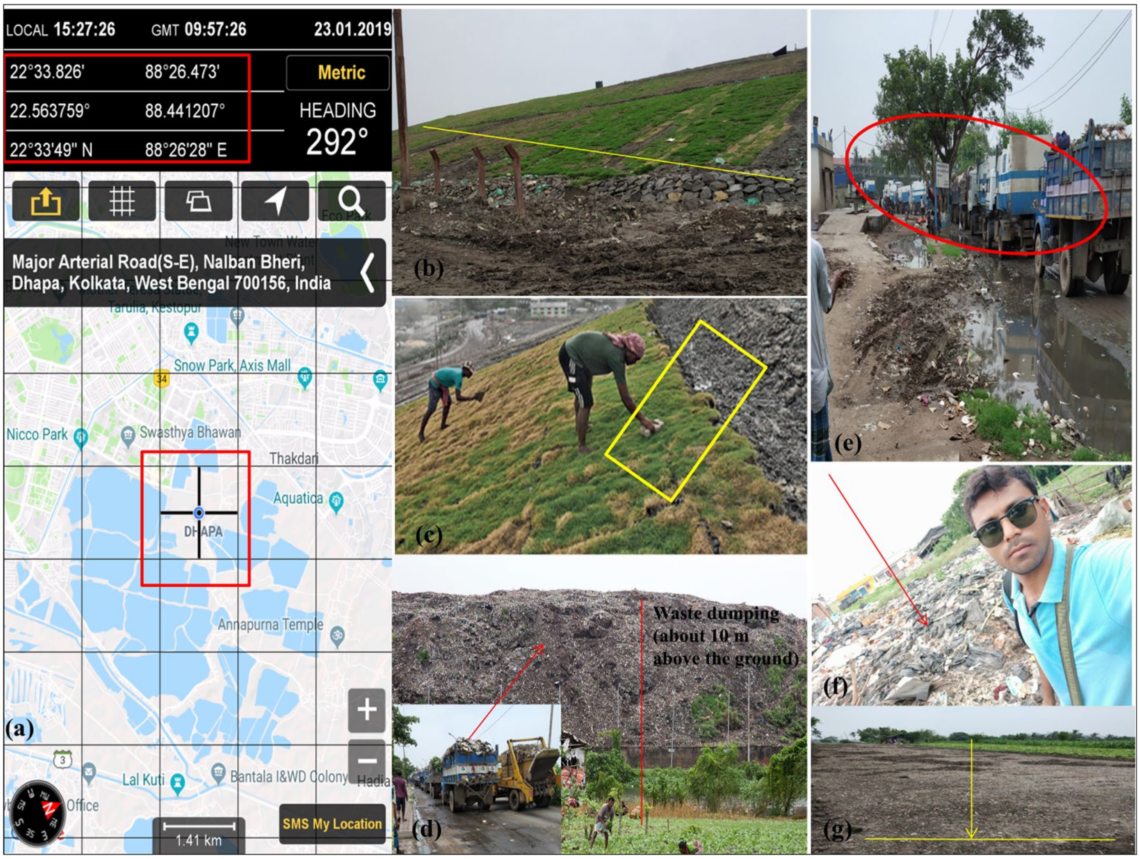

Fig. 3 **a** Location of GPS point near Dhapa, taken during determining best site by considering public acceptance and environmental issues after suitability analysis; **b** closed dump site, plan for a recreational park; **c** labors working at closed dump for constructing the park; **d** waste dumped about 10 m above ground at active dump site, Dhapa; **e** waste transporting vehicles and compactors standing long before unloading waste; **f** author during field visit near Dhapa dumping ground; **g** vacant land nearby Dhapa, East Kolkata Wetland (EKW), can be considered as a suitable place for new landfill site

The reasons for the selection of these criteria are discussed below.

Hydrological criteria

For siting landfills, it is required to keep a certain distance from water sources. Several studies used specific distance for analyzing landfill site suitability ranging from 100 to 300 m for surface water like lakes, ponds (Chang et al. 2008; Gorsevski et al. 2012; Ebistu and Minale 2013), river (Gemitzi et al. 2006; Akbari et al. 2008; Ebistu and Minale 2013; Gorsevski et al. 2012), canal (Jaybhaye et al. 2014), and wetlands (Chang et al. 2008). Looking towards the hydrological profile of the study area, four criteria, i.e., nearness to water bodies (ponds and lakes), wetlands, river, and canals were selected for proximate analysis. Water bodies like lakes, pond, river, canal, wetlands, etc. are more susceptible to contamination due to unscientific landfill and disposal sites must not be located near river, stream, and surface water (Paul 2012). Hence, landfill should not be sited in or near to surface water bodies and keep certain distances to reduce surface water contaminants. However, the main issue in KMC is a scarcity of land. The current land-use classification (Fig. 5a) shows that more than 90% of its area is built-up and less than 10% is the other group of land cover. Therefore, in case of no alternative best sites in other parts of the city, the surface water bodies like ponds, and wetlands could be considered for future sanitary landfill sites, because present waste dumping site itself is the part of wetlands and it was selected due to not finding suitable places that can fulfil all specification of landfill siting criteria.

The input layers of selected criteria related to hydrology were created in a GIS environment using GPS location, SOI toposheets, satellite imagery, and Google earth open software. Vector layer of each criterion (e.g., surface water, river, canal, and river) was first created and exported in a GIS environment for proximate analysis. 200 m interval was used for river, canal, and wetlands and 100 m for surface water including ponds, lake, and other water sources. These vector layers were converted into a raster layer (V2R) and

Table 1 Criteria selected and decision-making approaches applied for landfill site suitability at global scale

S.N	Study area	Criteria considered for landfill site suitability evaluation	Technique applied	Authors
1	Thailand	Groundwater well, school, village, temple, built-up area, archeological sites, perennial stream, intermittent stream, pond, forest, orchard, road, slope, lineament, elevation	Fuzzy set theory and AHP	Charnpratheep et al. (1997)
2	Lemnos Island, Aegean Sea, Greece	Water permeability, dis to water sources, surface water, sensitive ecosystems, land cover, urban areas, cultural areas, land uses, visibility criteria, morphology, wind orientation	Simple Additive Weighing (SAW) and Analytic Hierarchy Process (AHP)	Kontos et al. (2005)
3	The Lower Rio Grande Valley, the southernmost tip of Texas	Distance to rivers, lakes, wetland, land use/land cover, roads, ground water wells, urban areas, soil maps, digital elevation model	Fuzzy MCDM	Chang et al. (2008)
4	Bandar Abbas, Iran	Surface water sources, water wells, urban and rural areas, agricultural and industrial centers, coastal zone, road network, elevation, slope, faults	GIS and Fuzzy Multi Criteria Decision Analysis	Akbari et al. (2008)
5	Istanbul, Turkey	Proximity to industrial solid waste, Proximity to household solid waste, Transportation, Proximity to residential area	Fuzzy TOPSIS and AHP	Onut and Soner (2008)
6	City of Petropolis, Rio de Janeiro, Brazil	Soil Permeability, dis. to surface water bodies, depth to the ground water level, dis. to airports, dis. to residential areas, lifetime, ground slope, extension of drainage basin, land use, land cost, occupation of access routes, problems with local communities, access to heavy trucks, dis. from the collect center	Fuzzy MCDM	Alves et al. (2009)
7	The Polog Region, Republic of Macedonia	Slope, elevation, dis. to rivers, dis. to lakes, dis. to spring, Land use, hydrology, dis. to fault, dis. to urban and rural areas, proximity to roads, proximity to building materials, proximity to dense population	Fuzzy set theory and analytic hierarchy process (AHP)	Donevska et al. (2011)
8	Eldoret Municipality, Kenya	Rivers, land use, road and railway network, urban areas, digital elevation model (DEM), slope,	GIS and multi-criteria analysis (MCA)	Ouma et al. (2011)
9	The Republic of Cape Verde	Waste transportation costs, dis. to electrical grid, dis. to coast line, land orientation, land cover, dis. to road network, terrain slope, terrain elevation, dis. to urban centers, land-use type	Analytic Hierarchy Process (AHP)	Tavares et al. (2011)
10	Polog Region, Republic of Macedonia	Slope, elevation, dis. to rivers, dis. to lakes, dis. to spring, land use, hydrology, dis. to fault, dis. to urban and rural areas, proximity to roads, proximity to building materials, proximity to dense population	Analytical hierarchy process (AHP) and ordered weighted average (OWA)	Gorsevski et al. (2012)
11	Thrace region, Greece	Aquifers vulnerability, seismic hazard assessment, soils permeability, slopes, elevation, soil texture, protected areas, surface water, pluviometry, temperature, land use, residential areas, transportation network, waste consumption source, road network	Multi-criteria spatial decision support systems (MC-SDSS) based AHP and TOPSIS	Demesouka et al. (2013)

Table 1 (continued)

S.N	Study area	Criteria considered for landfill site suitability evaluation	Technique applied	Authors
12	Pune Municipal Corporation	Distance to road network, rivers, lakes, canals, geology, population density, slope, airport, land use/land cover	Multi-criteria analysis technique (AHP)	Jaybhaye et al. (2014)
13	Istanbul	Haul distance, restriction sites, land use, soil structure, geological condition, hydrology, surface water, local climate, wind direction, transportation lines, proximity to building materials, land prices	Fuzzy AHP and fuzzy TOPSIS	Beskese et al. (2015)
14	Bardaskan, Iran	Geology, faults, land use, surface water, ground water, conserved area, slope, roads	Fuzzy Logic and Geographic Information Systems	Khorram et al. (2015)
15	Yasouj City, Iran	surface waters, wells, springs, qanats, Geology, slope, aspect, land use, Land cost, residential areas, road accessibility, soil depth, temperature, precipitation, wind	Analytic Hierarchy Process (AHP)	Eskandari et al. (2016)
16	Casablanca region, Morocco	Land cost, transportation, residential areas, historical places, ground water, soil type, infrastructure cost, dis to wells	Fuzzy AHP and fuzzy TODIM	Hanine et al. (2016)
17	Mumbai, India	Hydrology, sensitive areas, soil and topography, inhabited areas, flora and fauna, climate, fracture and faults, public acceptance, adjacent land use, intra-municipality, cost of site, road network/access, site capacity	Integrated fuzzy MCDM	Kharat et al. (2016)
18	Iranshahr, Iran	Lithology, alluvial deposits, land use, settlement, roads, morphology/topography, surface water, wind	GIS and fuzzy AHP	Torabi-Kaveh et al. (2016)
19	Al-Musayiab Qadhaa, Babylon, Iraq	Groundwater depth, rivers, soil types, agriculture land, land use, elevation, slope, gas pipelines, oil pipelines, power lines, roads, railways, urban centers, villages, archeological sites	Combined analytic hierarchy process (AHP) and simple additive weighting (SAW)	Chabuk et al. (2017)
20	Istanbul	Land use, geology, settlement areas, surface waters, population density, airports, protected areas, slope, solid waste transfer stations, land values, highways	Analytic hierarchy process (AHP) and GIS	Guler and Yomralıoglu (2017)

reclassified with a scale value of 1–5. Here, 1 indicates the least suitable and 5 indicated highly suitable for municipal landfill site (Fig. 4).

Topographic and climatic criteria

Topography and climate are the important factors which should be considered for assessment before going to site municipal landfill (Al-Yaqout and Hamoda 2003; Yesilnacar and Cetin 2005, 2008). The topographic and climatic variations of KMC were considered, because the east–west extent of this riverbank city was once parts of wetlands and expansion take place day after day. Thus, four topographic and climatic criteria including land elevation, land slope, land surface temperature, and no. of average rainy days were selected to evaluate for the suitable municipal landfill site.

The slope is the measure of the rate of change of elevation of surface location (Chang 2018). Elevation and slope are considered as the basic criteria for landfill site selection. These criteria have an inverse relation with landfill suitability, i.e., as the degree of slope and height of elevation increases, the suitability of an area for a landfill site will decrease (Kontos et al. 2005). Different studies prove that area with a steep slope will have a high risk of pollution, leachate, and potentially not suitable for dumping site (Ebistu and Minale 2013). The land surface where the slope is more than 25° is not considered as suitable for landfilling (Guler and Yomralıoglu 2017). The land with a slope less than 10° is highly suitable for landfill site (Leao et al. 2001; Nas et al. 2010). From an economic point of view, the land with a high elevation and the steep slope will lead to more excavation costs than flat land (Guiqin et al. 2009).

In climatic criteria, surface temperature and rainfall were considered for spatial evaluation in landfill site selection. Areas with more than 650 mm rainfall are not suitable for landfilling (Udomporn et al. 2009; Babalola and Busu 2011). The rate of infiltration is largely depending upon rainfall. Infiltration is an important factor in evaluating the potential risk of groundwater contamination which is increased and decreased by rainfall and surface runoff. Thus, it is a major criterion which should be considered for the framework development of the landfill. Temperature helps in the burning process with the presence of methane (CH_4) in the landfill site which causes degradation of the surrounding environment. Therefore, areas with high rainfall, evapotranspiration, and temperature are not suitable for waste landfill location (Babalola and Busu 2011).

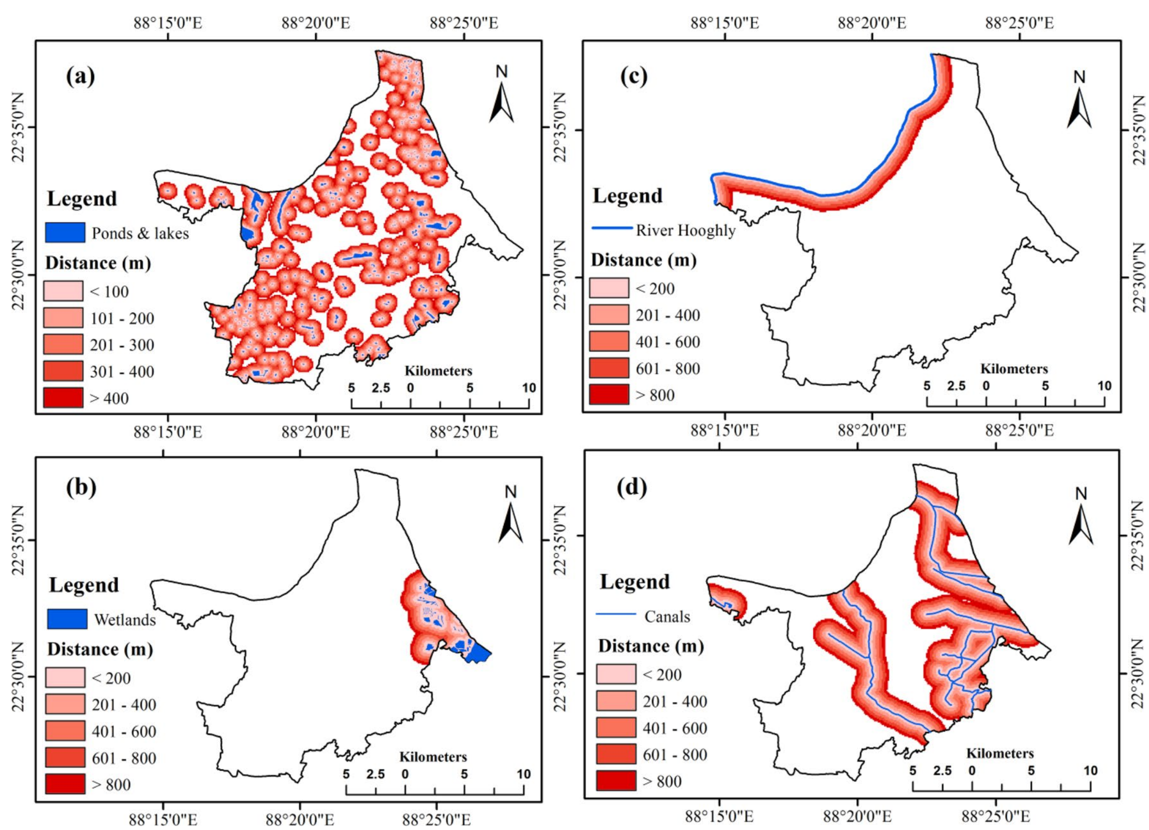

Fig. 4 Selected hydrological criteria: **a** nearness to water bodies like ponds and lakes; **b** nearness wetlands; **c** nearness to river; **d** nearness to canals

The SRTM DEM data of the study area were used to estimate the land elevation and slope map. The elevation of the study area ranges from < 1 m to > 13 m and slope varies from > 1° to > 12°. The low elevation and low degree of the slope were considered as suitable for landfill location (Fig. 5a, b). The rainfall map was prepared using the data collected from the local weather report, meteorological station Kolkata, Alipore. Station-wise average no. of rainy days was collected. These data were converted into geo-database and spatial rainfall map was prepared using the widely used method i.e. IDW (inverse distance weighted) in a GIS environment (Setianto and Triandini 2013). The spatial data on average no. of rainfall days of the study area range from 72 to 85 (Fig. 5d). The areas with least no. of rainfall days was considered as more suitable, while areas with greater no. of rainfall days as not suitable for municipal landfill. The surface temperature was extracted from Landsat 8 TIRS data of the study area. The radiative transfer equation (RTE)-based method was used with band 10 for retrieving land surface temperature (Yu et al. 2014). Areas encircling low temperature were considered as best and high-temperature areas as least suitable for landfill siting (Fig. 5c). The following equation was used in the raster calculator for the same. First thermal sensor data (TIR) were converted into the top of atmosphere spectral radiance using the following equation expressed as:

$$L_\lambda = M_L \times Q_{\mathrm{cal}} + A_{L,} \tag{1}$$

where L_λ is the top of atmosphere (TOA) spectral radiance [Watts/(m^2 × srad × μm)], M_L is the band-specific multiplicative rescaling factor, Q_{cal} is the quantized and calibrated standard product pixel value and A_L is the band-specific additive rescaling factor.

Then, brightness temperature was calculated from the reflectance value which is expressed by the following equation:

$$\mathrm{BT} = \frac{K2}{In\left(\frac{K1}{L_\lambda} + 1\right)} - 273.15, \tag{2}$$

where BT is the atmospheric brightness temperature, $K1$ and $K2$ are the band-specific thermal conversion constant taken from metadata file, and L_λ is TOA spectral radiance. The value was subtracted by 273.15 to convert it from kelvin to degree Celsius.

Finally, BT was converted into land surface temperature using the simple equation:

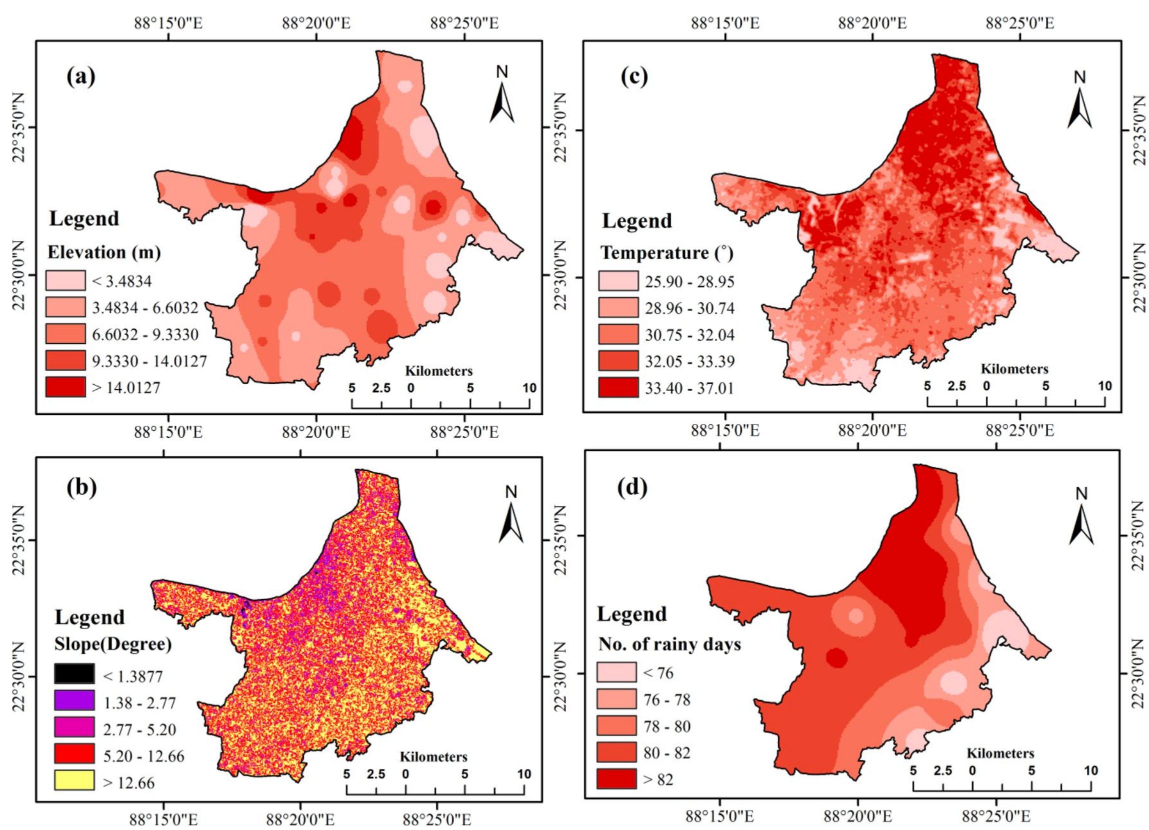

Fig. 5 Selected topographic and climatic criteria: **a** land elevation; **b** slope in degree; **c** surface temperature; **d** average no. of rainy days

$$LST = (BT / (1 + (\lambda \times BT / c2) \times Ln(e))), \quad (3)$$

where λ is the wavelength of emitted radiance, c2 is the h × c/s = 1.4388 × 10^2 m K = 14,388 μm (h, c, and s are constant), and e is the emissivity which was calculated from NIR and Red band Landsat 8.

Land criteria

Land features are the most significant factor for selecting a suitable landfill site. A particular type of activities on land and their characteristics must be considered before selecting any land portion for the municipal landfill site. Thus, looking towards the land features of the study area, four important criteria were selected. These were land use and land cover, geomorphic structure, soil moisture, and nearness to agricultural land.

Among the land features, the land use and land cover were considered as the most important criteria for siting landfill. Specific type of land cover like forest areas, water bodies, wetlands, nearness to settlement, dense populous, and high build index areas are not suitable for landfilling to protect public health and environmental hazards (Gorsevski et al. 2012; Jaybhaye et al. 2014; Guler and Yomralıoglu 2017). As far as the land use of the study area is concerned, the maximum portions covered with the high built-up area, the proportion of vegetation and water bodies are also high in comparison to fallow land and open space. Thus, it is really a challenging task to find suitable landfill site based on land use, because fallow land and open space are considered as the best suitable site in comparison with another land-use type (Fig. 6a).

Geomorphic structure and soil moisture were also considered as important land features. Geomorphic structures were classified into four types based on groundwater information booklet, Kolkata Municipal Corporation, West Bengal (Ground water information booklet 2007). Among these four types including younger levee, older levee, inter-distributor marshes, and deltaic plains, only older levee can consider for suitable landfilling, because younger levee and inter-distributor marshes have greater infiltration capability, whereas deltaic plains are mainly occupied by residential and built-up area (Fig. 6b). The soil moisture index is truly related to geomorphic structure. Generally, areas with inter-distributor and marshes younger levees have greater moisture content. The soil moisture index (SMI) map was prepared from satellite image (Landsat 8 OLI and TIRS). A higher value of SMI indicates surface with high moisture content and less suitable for landfill site, concomitantly lower value indicates low moisture in land and greater suitable for landfilling (Fig. 6c).

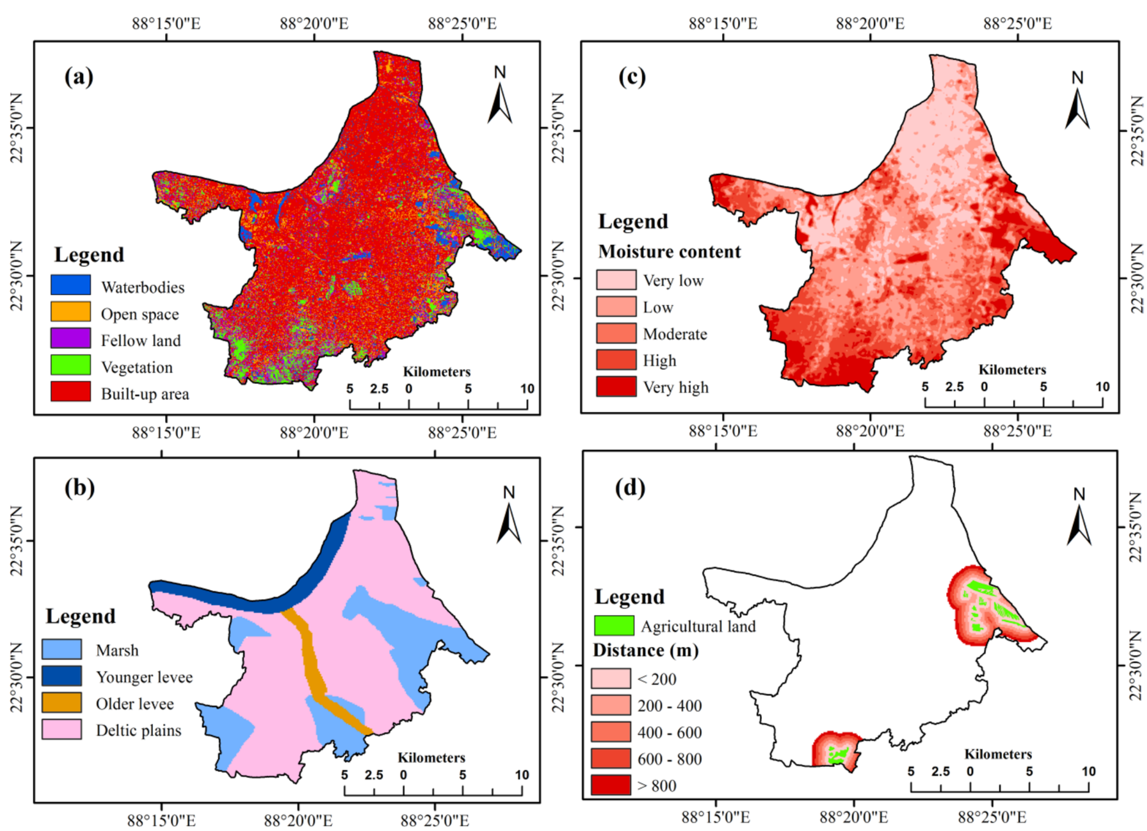

Fig. 6 Selected land criteria: **a** land use and land cover; **b** geomorphic structure; **c** moisture content in soil; **d** nearness to agricultural land

SMI is the empirical penetration of relationship between normalized difference vegetation index (NDVI) and land surface temperature (Zeng et al. 2004; Parida et al. 2008; Wang and Qu, 2009). Soil moisture index is defined as:

$$SMI = \frac{LST_{max} - LST}{LST_{max} - LST_{min}}, \quad (4)$$

where LST_{max} and LST_{min} are the maximum and minimum temperature retrieved from given NDVI. LST_{max} and LST_{min} are calculated using the following equation:

$$LST_{max} = a_1 \times NDVI + b_1 \quad (5)$$

$$LST_{min} = a_2 \times NDVI + b_2, \quad (6)$$

where a_1 and a_2 are the highest and lowest NDVI, and b_1 and b_2 are the highest and lowest surface temperature.

Along with these three criteria, agricultural land was also chosen as land features. Leachates and poisonous waste from landfill degrade the natural quality of soil and running through the food chain to intake group (Gworek et al. 2015; Adamcová et al. 2016). Thus, landfill should not be located nearer to cultivated or agricultural lands. Polygon-based shapefile of agricultural lands was created with the help of satellite imageries and Google earth software for proximate analysis. With a common interval of 200 m, multiple ring buffers were created and areas close to agricultural lands were considered as unsuitable and farther as suitable for landfilling (Fig. 6d). These agricultural lands in KMC are not too much product and only use for vegetation cultivation. Thus, in case of no alternative suitable sites in other parts of the city, these lands could be considered for future sanitary landfill sites.

Criteria related to accessibility

Accessibilities are the most important component of urban services which helps the quality of being able to be reached or entered. As per the guidelines of the pollution control board, the landfill site should not be located near to road, rail, and metro ways. Hence, a certain distance from these features should keep before going to site a suitable landfill location. Four accessibility-related factors, i.e., nearness to national and state highways, major road networks, railways, and metro ways were taken into consideration. Several studies assigned higher suitability rank close distance to road network from economic point of view to lessen the transport cost (Guiqin et al. 2009; Gorsevski et al. 2012; Das and Bhattacharyya 2015; Guler and Yomralıoglu 2017). Some studies used higher rank far distance to road network from an environmental point of view (Bhambulkar 2011; Rafiee et al. 2011; Jaybhaye et al. 2014). The previous studies also revealed that the waste disposal site should not be located nearer to the road and other communication networks (Akbari et al. 2008; Babalola and Busu 2011).

The present study considered an environmental point of view and assigned lower rank closer to road, rail, and metro network. Satellite images and Google earth Pro were used to create features shapefile of these four selected features and imported as KML to layer in GIS environment for proximate analysis. Due to variations in density and distribution, the major roads were buffered with a common interval of 100 m, national and state highways with 300 m, and railways and metro ways with 250 m. Among the five categories of each criterion, the higher value of rank was put to far distant and lower value of rank to the closer distance for siting suitable solid waste landfill (Fig. 7).

Criteria related to infrastructure

Infrastructure means the necessary facilities and systems serving a city. The population is an important component of infrastructure, because dense population and high built-up areas are confined nearer to areas of better facilities. Before going to select suitable sites for landfilling, it is required to assess and keep a certain distance from criteria related to infrastructure. The present study assessed four related criteria including the density of population, built-up index, nearness to restricted sites, and nearness to sensitive sites to find a suitable location for the municipal landfill site.

The result of several types of research has revealed that many issues of public opposition for siting landfill sites decrease on increasing distance from built-up and residential areas and concomitantly suitability score of landfill increasing with decreasing public oppositions (Lober 1995; Mahini and Gholamafard 2006). Therefore, waste landfill sites should not be located in densely populated urban or rural areas (Babalola and Busu 2011; Donevska et al. 2011; Demesouka et al. 2013). The same cases also applicable with respect to restricted and sensitive sites and should not be located landfill sites near to any are and sensitive places (Kontos et al. 2005; Guler and Yomralıoglu 2017). Thus, within 100 m of these places are considered unsuitable for landfilling, and distance further is considered as suitable (Babalola and Busu 2011).

Spatial map of population density was prepared using the latest data collected from District statistical handbook 2014–15, Bureau of Applied Economics & Statistics, Department of Statistics and Programme Implementation, Government of West Bengal. The population density was classified into five categories from very high to very low. Above 10 lakhs population/Km^2 was taken as very high category and considered as unsuitable for landfill site location. On the other hand, population below 28 thousand/Km^2 was considered as the very low density of population and suitable for landfilling (Fig. 8a). The built-up index was prepared

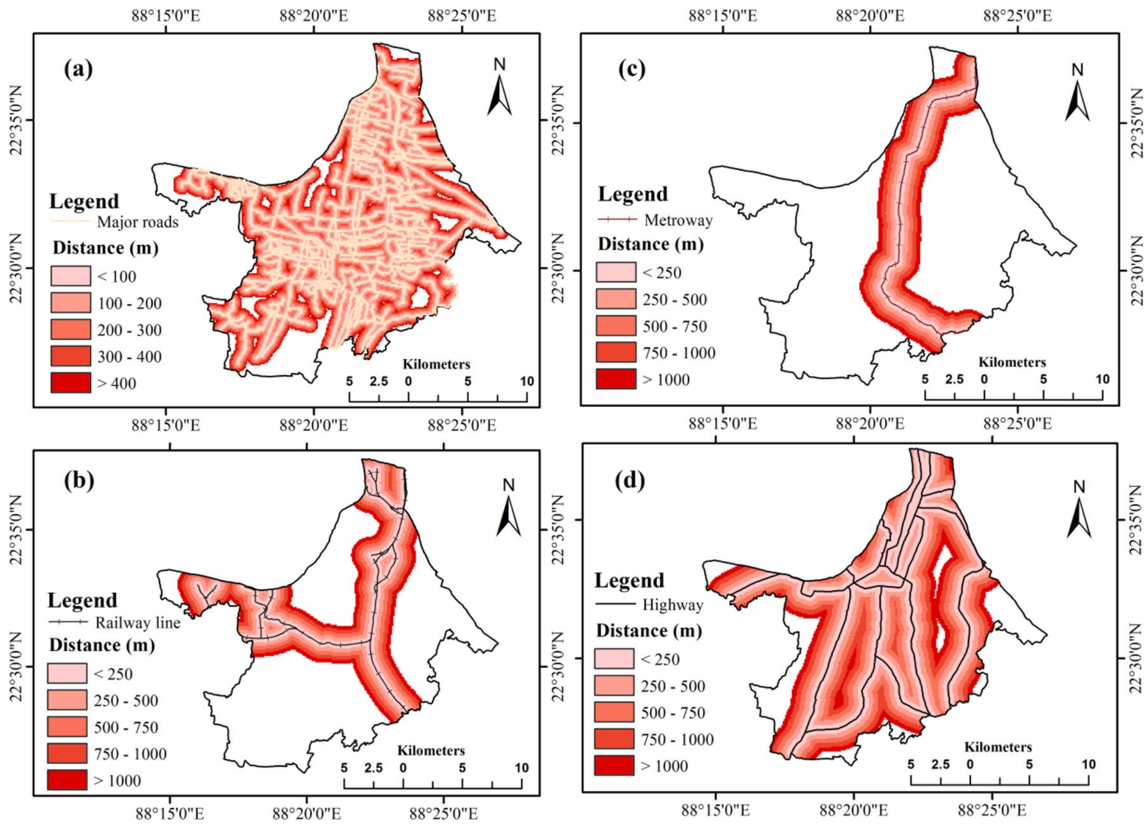

Fig. 7 Selected criteria related to accessibility: **a** proximity to major road network; **b** proximity to railway line; **c** proximity to metro way; **d** proximity to highway

using the satellite data of Landsat 8 OLI to show areal differentiation in terms of built-up areas. SWIR and NIR bands of Landsat 8 were considered to calculate the normalized difference built-up index (NDBI) using the following equation (Xu 2007; Bhatti and Tripathi 2014):

$$\mathrm{NDBI} = \frac{\mathrm{SWIR} - \mathrm{NIR}}{\mathrm{SWIR} + \mathrm{NIR}}, \quad (7)$$

where SWIR is the short-wave infrared band (Band 7 was taken) and NIR is the near-infrared band (Band 5).

For the study area, NDBI value ranges from − 0.4793 to + 0.2428. The plus value indicates a highly built area and should not be considered for landfill sites. Whereas, the minus value of NDBI indicates area under low built-up which may be considered as a suitable landfill site (Fig. 8b). Along with densely populated and high built-up areas, restricted and sensitive places were also considered. Restricted places like historical places, museum, parks, local Sudan, etc. and sensitive places like schools, colleges, universities, institutions, medical hospitals, residential hostels, banks, post offices, temples, churches, and masques were taken for proximate analysis. For the same, point shapefiles were created using place layer in Google earth professional version. These identified points were exported into GIS environment and multiple ring buffers were created with 100 m interval from sensitive places and 200 m interval from restricted places. The areas closer to restricted and sensitive places were considered as least suitable and further distance as highly suitable for municipal landfill site (Fig. 8c, d).

Weight calculation using fuzzy analytic hierarchy process (FAHP)

The pollution control board has set up predefined criteria and specific distance for setting the suitable location of the landfill site. Hence, the study is required to select multiple alternatives and criteria (Gorsevski et al. 2012; Demesouka et al. 2013; Ebistu and Minale 2013; Feo and Gisi 2014; Jaybhaye et al. 2014; Beskese et al. 2015; Hanine et al. 2016; Guler and Yomralioglu 2017; Chabuk et al. 2017). From the environmental point of view, different component nearness to landfill site has a vulnerability and each factor or criteria is not equally vulnerable to risk due to landfill. Thus, criteria-based comparison and weight should be calculated. As far as multi-criteria analysis is concerned, there are various techniques for weighting selected criteria or factors like weighted sum model (WSM), weighted product model (WPM), weighted aggregated sum product assessment

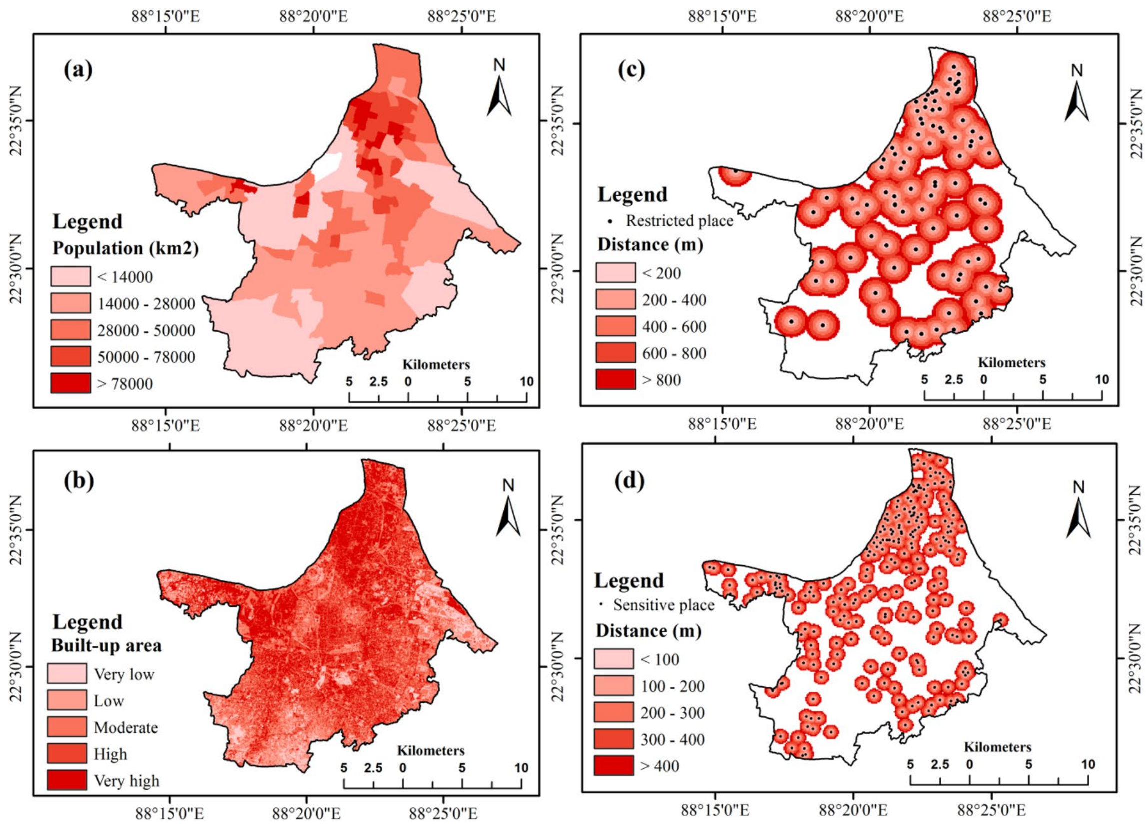

Fig. 8 Selected criteria related to infrastructure: **a** population density; **b** built-up area; **c** nearness to restricted places; **d** nearness to sensitive sites

(WASPAS), technique for order preference by similarity to ideal solution (TOPSIS), analytic hierarchy process (AHP), entropy method, evaluation based on distance from average solution (EDAS), fuzzy analytic hierarchy process (FAHP), fuzzy TOPSIS, etc. (Kontos et al. 2005; Onut and Soner 2008; Tavares et al. 2011; Beskese et al. 2015; Demesouka et al. 2013; Khan and Samadder 2015; Torabi-Kaveh et al. 2016; Chabuk et al. 2017; Guler and Yomralioglu 2017).

Among these used techniques, AHP and fuzzy gained wide popularity (Chang et al. 2008; Alves et al. 2009; Gorsevski et al. 2012; Afzali et al. 2014; Lima Junior et al. 2014; Beskese et al. 2015; Bahrani et al. 2016; Kharat et al. 2016). The analytic hierarchy process was introduced by Saaty (1980) which is considered as the best technique for tackling complex MCDM (multi-criteria decision-making) problems in real situations. Literature has proved that AHP is very useful for decision-making and suitability analysis (Şener et al. 2010a, b; ZelenovićVasiljević et al. 2011; El Baba et al. 2015). But practically, the uses of a crisp numeric value in AHP are often inadequate, because human judgment may be biased and vague. However, to overcome such a shortage of AHP, Van Laarhoven and Pedrycz proposed fuzzy AHP in 1983, which is the combination of AHP and Fuzzy set theory. A fuzzy set is the most preferred theory in multi-criteria decision-making (Hanine et al. 2016). A fuzzy set is an extended form of ordinary set theory that was introduced by Zadeh in 1965 for dealing with business, vagueness, and uncertainty in the data set (Beskese et al. 2015). Looking toward this advantage, fuzzy AHP (FAHP) was used in the present study for the deriving weight of selected criteria.

The FAHP makes it possible to use a fuzzy number instead of using crisp numeric value. The study found that in AHP, decision-makers tend to use interval judgment instead of fixed judgment (Büyüközkan and Ruan 2008). However, fuzzy in AHP deals with ambiguous and uncertainty information (Balli and Korukoglu 2009). Literature shows that there are different procedures to derive weight using fuzzy AHP (Bozbura et al. 2007). Among these, the geometric mean method proposed by Buckley (1985) and extent analysis method proposed by Chang (1996) are the most popular and widely used. In the present study, the extent analysis method introduced by Chang was applied with triangular fuzzy numbers (TFNs) to calculate the fuzzy weight (Chang 1996).

Fuzzy extent analysis

The fuzzy set theory incorporated with original AHP to deal vagueness of human judgment in the decision-making process. With the application of triangular fuzzy numbers

(TFNs), pairwise comparison scale of FAHP was calculated and the synthetic extent value of Si calculated with the use of extent analysis method (Chang 1996). The details of Chang's extent analysis method on FAHP for calculating the weight of selected criteria have been described in the following steps (Vahidnia et al. 2009; Wang and Chin 2011; Boutkhoum et al. 2015; Efe 2016; Hanine et al. 2016). For the present case, suppose that A (a_1, a_2 ….. a_n) is the object set and J (j_1, j_2 …… j_m) is the goal set. Using Chang's method of extent analysis, each goal (j_i) is performed by taking each object (a_i) on the extent analysis (Chang 1992, 1996). Thus, m extent value for each object can be obtained which is expressed as:

$$M_{ai}^1, M_{ai}^2, \ldots, M_{ai}^m \quad (8)$$

where $i = 1, 2, 3, \ldots\ldots, n$ and all M_{ai}^m are the triangular fuzzy numbers ($j = 1, 2, \ldots\ldots, m$).

With respect to the ith object, the fuzzy synthetic extent value (S_i) is expressed as:

$$Si = \sum_{j=1}^{n} \tilde{a}ij \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} \tilde{a}ij \right] - 1. \quad (9)$$

It involves the calculation of $\sum_{j=1}^{n} \tilde{a}\, ij$ through the addition of two fuzzy numbers, the operation of $\tilde{a}$ extent values obtained of a particular matrix using the following equation:

$$Si = \sum_{j=1}^{m} \tilde{a}ij = \left(\sum_{j=1}^{m} lj, \sum_{j=1}^{m} mj, \sum_{j=1}^{m} uj \right). \quad (10)$$

And to get the $\left[\sum_{i=1}^{n} \sum_{j=1}^{m} \tilde{a}ij \right]$-1, perform the fuzzy addition function, which is expressed as:

$$\sum_{i=1}^{n} \sum_{j=1}^{m} \tilde{a}ij = \left(\sum_{j=1}^{m} lj, \sum_{j=1}^{m} mj, \sum_{j=1}^{m} uj \right) \oplus \left(\sum_{i=1}^{n} lj, \sum_{i=1}^{n} mj, \sum_{i=1}^{n} uj \right), \quad (11)$$

where l = lower limit value, m = middle limit value, and u = upper limit value. By summing the set of l, m, and u, the values of the fuzzy pair-wise comparison matrix are obtained. This is expressed as:

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} \tilde{a}ij \right] - 1. \quad (12)$$

Then, the inverse of the vector is calculated as:

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} \tilde{a}ij \right] - 1 = \left(\frac{1}{\sum_{i=1}^{n} uj}, \frac{1}{\sum_{i=1}^{n} mj}, \frac{1}{\sum_{i=1}^{n} lj} \right). \quad (13)$$

After the calculation of fuzzy synthetic extent values (S_1, S_2,….. S_n), the degree of possibility has to calculate. The degree to possibility of $M_2 = (l_2, m_2, u_2) \geq M_1 = (l_1, m_1, u_1)$ is expressed as:

$$V(M_2 \geq M_2) = \sup_{y \geq x} \left[\min\left(\mu_{M_{1(x)}}, \mu_{M_{2(y)}} \right) \right] = hgt(M_1 \cap M_2) = \mu_{M_{2(d)}}, \quad (14)$$

where d is the ordinate of the highest intersection point between μM_1 and μM_2. The degree of possibility can be equivalently defined as:

$$\begin{cases} 1, & \text{if } m_1 \geq m_2 \\ 0, & \text{if } l_2 \geq u_1 \\ \frac{l_2 - u_1}{(m_1 - u_1) - (m_2 - l_2)}, & \text{otherwise} \end{cases}, \quad (15)$$

where l, m, and u are the lower, middle, and upper limits of the value of fuzzy synthetic extent. For the comparison between m_1 and m_2, we need both the values of V ($S_1 \geq S_2$) and V ($S_2 \geq S_1$) and it will increase depending upon the selected criteria (e.g. S_1, S_2, S_3, …….. S_n).

Now, calculate the degree of possibility for a convex fuzzy number to be greater than 'k' convex fuzzy number. That can be expressed by:

$$\begin{aligned} V\,[(S \geq S_1), (S \geq S_2), \ldots (S \geq S_k) \\ = \min\ (S \geq S_i),\ i = 1, 2, 3, \ldots k. \end{aligned} \quad (16)$$

Based on the above equation, calculate the weight vector and normalize the non-fuzzy weight value. This is supposed by:

$$d'\ (A_i) = \min V\ (S_i \geq S_k),\ i, k = 1, 2, 3, \ldots n,\ k \neq i. \quad (17)$$

Finally, the weight vectors are calculated using the following equation:

$$W' = \left(d'\ (A_1), d'\ (A_2), d'\ (A_3), \ldots d'\ (A_n) \right)^T, \quad (18)$$

where A_i ($i = 1, 2, 3, \ldots\ldots n$) and W' is the non-fuzzy weight.

Weighted overlay analysis (WOA)

In GIS application, the weighted overlay is the most applied approach for overlay analysis to solve multi-criteria problems. Where multiple factors are chosen to develop certain conclusion, weighted overlay offers the best result such as site selection and suitability models (Ayalew 2004; Belay et al. 2015; Roslee et al. 2017). Weighted overlay technique can be used in diversified field of study as the best location for expansion of towns (Belay et al. 2015), site-specific groundwater recharge (Kaliraj 2015); allocation of groundwater potential zone (Riad et al. 2011), crop suitability analysis (Jamil et al. 2018), disease susceptibility analysis (Ali and Ahmad 2019a, b), flood susceptibility and risk area estimation (Ali et al. 2019), landslide susceptibility analysis (Feizizadeh and Blaschke 2013; Basharat et al. 2016), suitable site for landfilling (Kontos et al. 2005; Akbari et al. 2008; Eskandari et al. 2016), etc.

In the present study, several criteria relating to landfill site selection were chosen. The weight of each criterion was calculated using fuzzy AHP. Raster layer of each criterion was assigned with a weight based on their role in the site selection of landfill and reclassified them into a common scale ranging from 1 to 5. Looking towards the criteria selected in the present study, the weighted overlay was done twice. First of all, the overlay was performed each of the main criteria category, i.e., hydrological criteria, topographic and climatic criteria, land criteria, criteria relating to accessibility, and infrastructure. Finally, the suitability of landfill site selection was performed by overlaying the suitability result of these output raster layers. For suitable landfill site selection, the weighted overlay can be expressed as:

$$S = \sum_{i}^{n} WiCi, \tag{19}$$

where S is the site suitability index for each layer, Wi is the weight of the ith criteria layer, Ci is the sub-criteria score of the ith criteria layer, and n is the number of suitability layers. The whole operation was carried out in a GIS environment.

Results

With the increasing quantity of daily waste generation and decreasing availability of land for waste disposal in KMC, it is a crucial task to manage excessive waste day by day. The present study attempted to analyze suitable sites for landfilling because the current landfill site of KMC will not bear any waste after 2–3 years. Hence, new and back-up landfill sites are required to identify. For the same, initially, factors which can influence and associated with the construction of landfill were selected and classified, and GIS layer was prepared. The total selected 20 criteria were considered into 5 main categories to weighted overlay and suitability modeling. Fuzzy AHP is a multi-criteria decision support technique which was used to derive the weights of selected criteria based on their relative importance and effectiveness in selecting suitable landfill sites (Table 2). The table shows that nearness to ponds/lakes and wetlands have the highest suitability weight among hydrological criteria with 0.5269 and 0.2935, respectively; degree of slope and land elevation among topographic and climatic criteria with 0.4502 and 0.4194, respectively; land use and soil moisture among land criteria with 0.3352 and 0.2925, respectively; nearness to major roads and highways among accessibility-related criteria with 0.4410 and 0.2838, respectively; nearness to sensitive and restrictive place among infrastructure-related criteria with 0.4639 and 0.3192, respectively.

The calculated weight based on overlay was performed to landfill suitability map that depicting a suitable location of municipal landfill candidate sites in KMC, India (Fig. 9). In Fig. 9, four alternative suitability models were given that prepared from weight-based overlay of different input criteria. Fuzzy synthetic extent and weight were calculated of five main criteria (hydrological, topographic and climatic, land, accessibility, and infrastructure-related criteria) by two or three output layers for final landfill suitability analysis and location of best sites (Table 3). Different criteria-based landfill suitability maps were grouped into two categories, i.e., not suitable for landfill and consider for suitable landfill. These suitability maps demarcate that suitable areas for landfill location are found in the east, southeast, and northwestern pockets of the study area, although the present landfill site (Dhapa dumping ground) is also located in the eastern part of the city which is the part of East Kolkata Wetlands (EKW). The study reveals that by considering the whole criteria specification, no suitable area is found in the study area for a new landfill location. But compromising with shallow water bodies, the little area can be considered for a new suitable landfill location. However, these suitable areas are also either part of wetlands or nearer to canals and surface water sources, because with high population density and high built-up area, it is really difficult to find vacant or fallow land for new landfill location. In case of not the availability of suitable land, alternatives sites like wetlands, lakes, etc. could be considered for only sanitary landfilling, not open dumping, because the functioning dumping ground in KMC is also part of the wetland.

One significant factor that not found in maximum literature available on the suitable location of municipal landfill sites using multi-criteria-based geospatial technologies, is after validation of result and community acceptance for the landfill in their locality or surroundings. Giving emphasis on that shortage, the effort was made to visit the places with GPS to judge current land use and the surrounding environment. Accepting public views and looking towards the environmental concern, some sites were rejected as suitable for the municipal landfill site. The following table presents a detailed of each of four site suitability maps with a number of suitable sites, area, and status of reject to further consideration for suitable municipal landfill (Table 4). The table shows that all suitable sites found from the present analysis are categorized into three classes, i.e., permissible, not available, and not suitable. Here, permissible indicates that site can be considered if no alternative sources found or in absence of alternative sources but by considering environmental concern and public acceptance, not available indicates in that place no suitable sites available for landfill and

Table 2 Pair-wise comparison of landfill site suitability criteria

Hydrological criteria							
	SWN	WLN	REN	CWN	Fuzzy synthetic extent	Fuzzy weight	Normalized weight
SWN	(1, 1, 1)	(2, 3, 4)	(3, 4, 5)	(2, 3, 4)	8, 11, 14	0.2592, 0.4730, 0.8428	0.5269
WLN	(0.25, 0.33, 0.5)	(1, 1, 1)	(2, 3, 4)	(1, 2, 3)	4.25, 6.33, 8.5	0.1377, 0.2721, 0.5117	0.2935
REN	(0.20, 0.25, 0.33)	(0.25, 0.33, 0.5)	(1, 1, 1)	(0.33, 0.5, 1)	1.78, 2.08, 2.83	0.0576, 0.0894, 0.1703	0.0799
CWN	(0.25, 0.33, 0.5)	(0.33, 0.5, 1)	(1, 2, 3)	(1, 1, 1)	2.58, 3.83, 5.5	0.0835, 0.1646, 0.3311	0.0996
Topographic and climatic criteria							
	LE	LS	LST	ARD	Fuzzy synthetic extent	Fuzzy weight	Normalized weight
LE	(1, 1, 1)	(0.25, 0.33, 0.5)	(2, 3, 4)	(2, 3, 4)	5.25, 7.33, 9.5	0.1905, 0.3589, 0.6156	0.4194
LS	(2, 3, 4)	(1, 1, 1)	(1, 2, 3)	(1, 2, 3)	5, 8, 11	0.1815, 0.3808, 0.7128	0.4502
LST	(0.25, 0.33, 0.5)	(0.33, 0.5, 1)	(1, 1, 1)	(1, 1, 1)	2.28, 2.83, 3.5	0.0827, 0.1347, 0.2268	0.0651
ARD	(0.25, 0.33, 0.5)	(0.33, 0.5, 1)	(1, 1, 1)	(1, 1, 1)	2.58, 2.83, 3.5	0.0936, 0.1347, 0.02368	0.0651
Land criteria							
	LULC	GS	SMI	AGN	Fuzzy synthetic extent	Fuzzy weight	Normalized weight
LULC	(1, 1, 1)	(2, 3, 4)	(1, 2, 3)	(1,1,1)	5, 7, 9	0.1760, 0.3192, 0.5499	0.3352
GS	(0.25, 0.33, 0.5)	(1, 1, 1)	(0.25, 0.33, 0.5)	(0.20, 0.25, 0.33)	1.7, 1.91, 2.33	0.0598, 0.0870, 0.1423	0.0368
SMI	(0.33, 0.5, 1)	(2, 3, 4)	(1, 1, 1)	(0.33, 0.5, 1)	4.66, 6, 8	0.1640, 0.2736, 0.4888	0.2925
AGN	(1, 1, 1)	(3, 4, 5)	(1, 2, 3)	(1, 1, 1)	5, 7, 9	0.1760, 0.3192, 0.5499	0.3352
Criteria related to accessibility							
	RWN	RLN	MWN	HWN	Fuzzy synthetic extent	Fuzzy weight	Normalized weight
RWN	(1, 1, 1)	(1, 2, 3)	(2, 3, 4)	(3, 4, 5)	7, 10, 13	0.2303, 0.4460, 0.8281	0.4410
RLN	(0.33, 0.5, 1)	(1, 1, 1)	(0.33, 0.5, 1)	(0.25, 0.33, 0.5)	1.91, 2.33, 3.5	0.0628, 0.1034, 0.2198	0.1401
MWN	(0.25, 0.33,0.5)	(1, 2,3)	(1, 1, 1)	(0.33, 0.5, 1)	2.58, 3.83, 5.5	0.0848, 0.1700, 0.3520	0.1349
HWN	(0.20, 0.25, 0.33)	(2, 3, 4)	(1, 2, 3)	(1, 1, 1)	4.2, 6.25, 8.33	0.1381, 0.2787, 0.5322	0.2838
Criteria related to infrastructure							
	PD	NDBI	RSN	SSN	Fuzzy synthetic extent	Fuzzy weight	Normalized weight
PD	(1, 1, 1)	(0.33, 0.5, 1)	(0.25, 0.33, 0.5)	(0.20, 0.25, 0.33)	1.78, 2.08, 2.833	0.0585, 0.0923, 0.1802	0.0749
NDBI	(1, 2, 3)	(1, 1, 1)	(0.33, 0.5, 1)	(0.25, 0.33, 0.5)	2.58, 3.83, 5.5	0.08488, 0.1700, 0.3509	0.1418

Table 2 (continued)

Criteria related to infrastructure							
	PD	NDBI	RSN	SSN	Fuzzy synthetic extent	Fuzzy weight	Normalized weight
RSN	(2, 3, 4)	(1, 2, 3)	(1, 1, 1)	(0.33, 0.5, 1)	4.33, 6.5, 9	0.1424, 0.2886, 0.5733	0.3192
SSN	(3, 4, 5)	(2, 3, 4)	(1, 2, 3)	(1, 1, 1)	7, 10, 13	0.2303, 0.4444, 0.8320	0.4639

SWN nearness to surface water (ponds, lakes), *WLN* nearness to wetlands, *REN* nearness to river, *CWN* nearness to canals, *LE* land elevation, *LS* slope, *LST* land surface temperature, *ARD* average rainy days, *LULC* land use and land cover, *GS* geomorphological structure, *SMI* soil moisture index, *AGN* nearness to agricultural land, *RWN* nearness to major roads, *RLN* nearness to railway line, *MWN* nearness to metro way, *HWN* nearness to highway, *PD* population density, *NDBI* normalized difference built-up index, *RSN* nearness to restricted place, *SSN* nearness to sensitive place

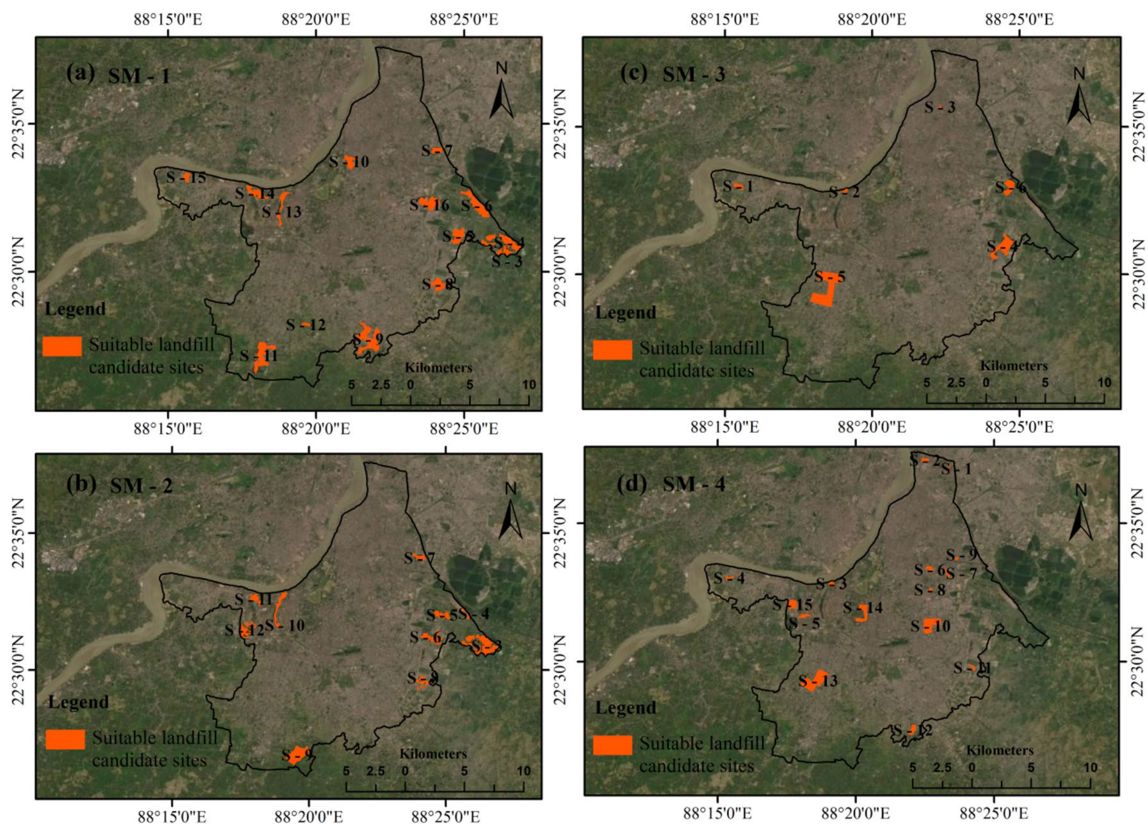

Fig. 9 Suitable candidate sites for sanitary landfill: **a** SM-1 (suitability model-1): overlay between HC, TCC, LC, AC, and IC; **b** SM-2 (suitability model-2): overlay between HC, AC, and LC; **c** SM-3 (suitability model-3): overlay between IC, AC, and TCC; **d** SM-4 (suitability model-4): overlay between TCC, LC, and IC

not suitable indicates that sites cannot be considered or permitted for landfill.

The present study reveals that some considerable sites were found for municipal sanitary landfill throughout the city. But after field investigation for knowing current land use, public views, and authority's decision, the maximum of these sites cannot be accepted as a suitable municipal landfill. In Fig. 9a, suitability model-1 shows that throughout KMC 16 sites were found for the suitable municipal landfill with an area ranging from 4 to 64 ha, but out of these 13 sites cannot be accepted for a landfill due to transportation issues, current land use, public acceptance, and local environmental issues. Only three sites can be considered for suitable landfill, although these are also in or near wetlands, but can be permitted, because present landfill site (Dhapa dumping ground) is itself a part of East Kolkata Wetland

Table 3 Pair-wise comparison of selected criteria for identifying final suitable landfill candidate sites

SM-1

4a	HC	TCC	LC	AC	IC	Fuzzy synthetic extent	Fuzzy weight	Normalized weight
HC	(1, 1, 1)	(1, 1, 1)	(0.25, 0.33, 0.5)	(0.33, 0.5, 1)	(0.25, 0.33, 0.5)	2.83, 3.33, 4	0.0657, 0.0102, 0.1715	0
TCC	(1, 1, 1)	(1, 1, 1)	(0.25, 0.33, 0.5)	(0.33, 0.5, 1)	(0.25, 0.33, 0.5)	2.83, 3.16, 4	0.0657, 0.0972, 0.1715	0.0174
LC	(2, 3, 4)	(2, 3, 4)	(1, 1, 1)	(1, 2, 3)	(1, 1, 1)	7, 10, 13	0.1627, 0.3077 ,0.5574	0.4367
AC	(1, 2, 3)	(1, 2, 3)	(0.33, 0.5, 1)	(1, 1, 1)	(0.33, 0.5, 1)	3.66, 6, 9	0.0850, 0.1846, 0.3859	0.1090
IC	(2, 3, 4)	(2, 3, 4)	(1, 1, 1)	(1, 2, 3)	(1, 1, 1)	7, 10, 13	0.1627, 0.3077, 0.5574	0.4367

SM-2

4b	HC	AC	LC	Fuzzy synthetic extent	Fuzzy weight	Normalized weight
HC	(1, 1, 1)	(0.33, 0.5, 1)	(0.25, 0.33, 0.5)	1.58, 2, 2.5	0.1019, 0.1738, 0.316	0.0828
AC	(1, 2, 3)	(1, 1, 1)	(0.33, 0.5, 1)	2.33, 3.5, 5	0.1503, 0.3004, 0.633	0.3370
LC	(2, 3, 4)	(1, 2, 3)	(1, 1, 1)	4, 6, 8	0.2580, 0.5214, 1.0128	0.5800

SM-3

4c	IC	AC	TCC	Fuzzy synthetic extent	Fuzzy weight	Normalized weight
IC	(1, 1, 1)	(1, 1, 1)	(3, 4, 5)	5, 6, 7	0.3190, 0.4444, 0.6139	0.2127
AC	(1, 1, 1)	(1, 1, 1)	(3, 4, 5)	5, 6, 7	0.3190, 0.4444, 0.6140	0.2127
TCC	(0.20, 0.25, 0.33)	(0.20, 0.25, 0.33)	(1, 1, 1)	1.4, 1.5, 1.66	0.0893, 0.1111, 0.1459	0.5744

SM-4

4d	TCC	LC	IC	Fuzzy synthetic extent	Fuzzy weight	Normalized weight
TC	(1, 1, 1)	(0.25, 0.33, 0.5)	(0.33, 0.5, 1)	1.58, 1.83, 2.5	0.1019, 0.1614, 0.3160	0.2127
LC	(2, 3, 4)	(1, 1, 1)	(0.33, 0.5, 1)	3.33, 4.5, 6	0.2147, 0.3969, 0.7594	0.2127
IC	(1, 2, 3)	(1, 2, 3)	(1, 1, 1)	3, 5, 7	0.1935, 0.4410, 0.8862	0.5744

SM suitability model, *HC* hydrological criteria, *TCC* topographic and climatic criteria, *LC* land criteria, *AC* criteria relating accessibility, *IC* criteria relating infrastructure

(EKW). Similarly, Fig. 9b, c, d (suitability model-2, 3, and 4) illustrate that maximum suitable sites resulted from the present geospatial-based analysis cannot be accepted for suitable municipal landfill, and for the same reason, these all were also excluded and very few sites can only be considered due to the absence of suitable alternatives sources. After considering all issues, it was found that about 28–30 ha area available for new municipal sanitary landfill sites that surrounding the current dumping ground (Fig. 10).

Discussion

Kolkata Municipal Corporation is the largest municipal bodies in Kolkata urban agglomeration. Due to its economic, commercial, and educational significance, the quantity of municipal waste generation has been increasing day by day. But for disposing of such a gigantic amount of waste, the availability of suitable lands is very scarce, because present dumping ground has no place to hold any waste after 2–3 years. In this regard, the present study utilized spatial information technologies and fuzzy analytic hierarchy process (FAHP) for selecting the ideal and suitable candidate sites for the study area. Initially, the study proposed a hierarchy model by considering information regarding environmental concern. Thus, hydrological, topographic and climatic, land features, access, and infrastructure were taken as the main criteria and selected 20 relevant criteria under these for supporting the decision in selecting suitable landfill candidate sites. Different studies utilized more or less similar criteria to build model and select landfill sites in rapidly growing cities of developing countries (Şener et al. 2010a, b; Ebistu and Minale 2013;

Table 4 Field investigation and suitability justification by considering public acceptance and environmental concern

Sites	Area (ha)	Land cover recognized through field visit	Suitability justification
Suitability mode-1			
1	7.3529	Beside wetland	*Permissible*
2	7.3527	Beside wetland and agricultural land	*Permissible*
3	14.0056	Near to wetland	*Permissible*
4	27.31078	In wetlands	Not suitable
5	28.3612	Aquaculture and nearby residents	Not suitable
6	41.3163	Dhapa dumping ground (current MSW dumping site)	Not available place
7	10.5041	Subhas sarovar lake	Not suitable
8	23.8094	Ponds, sparse residents, constructional site	Not suitable
9	64.7755	Sparse resident near Naktala	Not suitable
10	18.5573	Market area, nearby stadium and play ground	Not suitable
11	49.0193	Low density of population and vegetation cover	Not suitable
12	4.5517	Large ponds, jhils	Not suitable
13	18.2071	Canals	Not suitable
14	22.7589	Surface water bodies	Not suitable
15	9.4537	Sparse settlement	Not suitable
16	32.5623	Wetlands near Topsia	Not suitable
Suitability mode-2			
1	8.0719	Beside wetland	*Permissible*
2	10.1777	Near to wetland	*Permissible*
3	53.3453	In wetland	Not suitable
4	5.9662	Dhapa active dump (current MSW dumping site)	Not available place
5	19.3025	Aquaculture, agriculture	Not suitable
6	27.3745	Aquaculture, agriculture	Not suitable
7	12.9853	Subhas sarovar lake, residential area	Not suitable
8	15.4420	Ponds, constructional site, resident	Not suitable
9	54.7491	Agriculture, sparse vegetation	Not suitable
10	24.2159	Canal	Not suitable
11	14.7401	Water bodies	Not suitable
12	25.2688	Water bodies, fellow lands	Not suitable
Suitability mode-3			
1	6.9792	Sparse vegetation, low-dense resident	Not suitable
2	3.1406	Canal near to Hooghly river	Not suitable
3	1.0468	High resident near Hati bagan	Not suitable
4	41.8754	Aquaculture, constructional site, low resident	Not suitable
5	101.5481	Ponds, residential areas near Behala	Not suitable
6	40.4796	Seasonal agricultural land, wetlands	*Permissible*
Suitability mode-4			
1	3.9334	Market, residential area	Not suitable
2	4.2910	Market, residential area	Not suitable
3	3.9334	Navigable canal beside Hooghly river	Not suitable
4	6.0789	Sparse vegetation, low-dense resident	Not suitable
5	7.5093	Commercial place	Not suitable
6	7.1517	Residential, commercial place	Not suitable
7	5.3638	Residential, commercial place	Not suitable
8	2.1455	Constructional site, vegetate	Not suitable
9	1.4303	Dense residential, ponds	Not suitable
10	37.9042	Residential, commercial place near Ballygunje	Not suitable
11	4.6486	Agricultural, residential	Not suitable
12	10.3700	Ponds, sparse vegetation, low settlement	Not suitable
13	61.8625	Dense Settlement area	Not suitable
14	23.2431	Canals, vegetation, sensitive place	Not suitable
15	15.7338	Commercial zones	Not suitable

Permissible no public opposition is there and can be considered for new or back-up sanitary landfill sites, *not suitable* never consider for landfill site location, *not available place* this place can be considered for suitable landfill site but no more space available

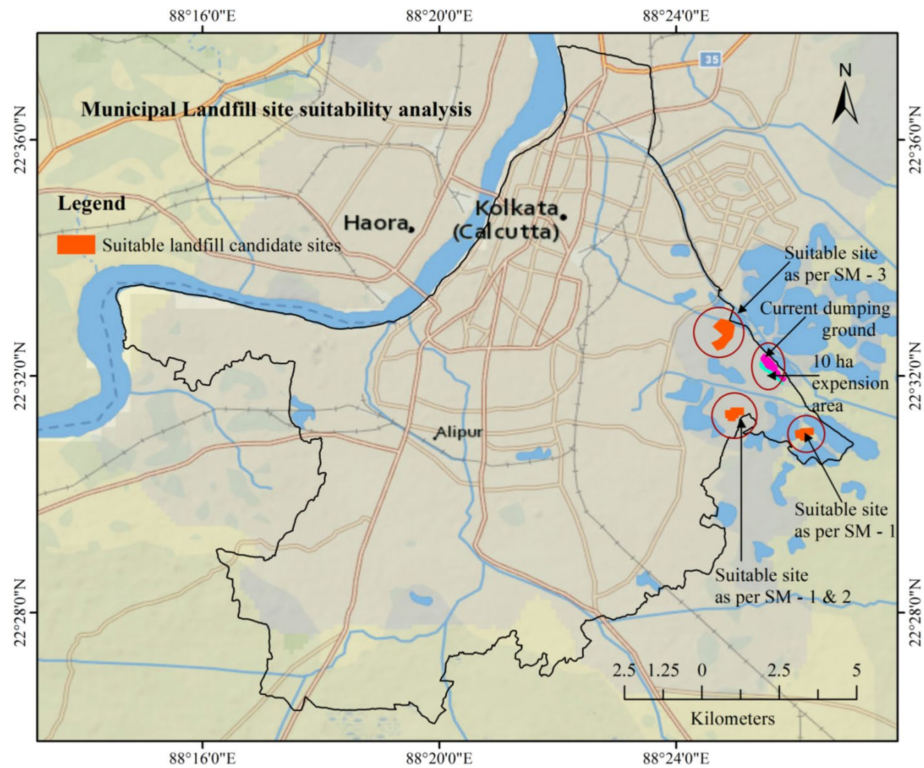

Fig. 10 Final suitable site selection for sanitary landfill site in KMC

Afzali et al. 2014; El Baba et al. 2015; Khan and Samadder 2015; Guler and Yomralioglu 2017).

Instead of selecting other techniques of multi-criteria, the present study used fuzzy AHP (synthetic extent analysis) to remove personal bias and ambiguity from decision support system during evaluating and weighting the selected criteria (Chang 1996; Chang et al. 2008; Alves et al. 2009; Balli and Korukoğlu 2009; Beskese et al. 2015). Expert-based decision support and classification scheme were applied for ranking the criteria. Such as when emphasizing land use and land cover, vacant and fellow land, i.e., un-usable lands were considered more suitable and assigned higher rank in comparison with high built-up and other usable lands (Kontos et al. 2005; Tavares et al. 2011; Jaybhaye et al. 2014). Again, for proximate analysis, areas nearer to 100 m or 200 m of selected criteria were considered unsuitable and assigned lower rank in comparison to areas far from selected criteria (Onut and Soner 2008; Donevska et al. 2011; Gorsevski et al. 2012).

Unlike the work of Wang et al. (2009), Gbanie et al. (2013), Jaybhaye et al. (2014), and Torabi-Kaveh et al. (2016) where suitable landfill sites were selected based on 8–10 sub-criteria by considering only two or three aspects of the main criteria, this study involved 5 main criteria and 20 sub-criteria by taking all aspects like hydrological, topographical, climatic, land features, accessibility, and infrastructures. The decision-making process becomes complex with increasing criteria, but the result may be more accurate with greater criteria. It should be pointed out that many studies excluded some criteria which try to interpret a significant factor for the location of landfill sites. Considering some more criteria in the present study and in cooperating with it into the site suitability model, resulted in increase in the number of sub-criteria to twenty. The following table shows cross-checks of using different alternatives for municipal landfill used in the present study that present or absent in the other studies (Table 5). These factors which are noticeably absent in the literature have a number of examples acceptable to the locals in the siting of a municipal landfill.

Unlike the work of Ouma et al. (2011), Gorsevski et al. (2012), and Demesouka et al. (2013), only geospatial-based suitable landfill sites were selected, the present study involved an after investigation of such output suitable sites. Sometimes, GIS and multi-criteria-based suitability analysis find some places that may not be acceptable for landfill because of local environmental concern and public issues. Thus, the present study made a post suitability field investigation for considering the final landfill candidate sites by taking local acceptance and environmental issues into consideration. What present study found more interesting was the selection of factors that noted the awareness and perception of people with respect to the location of municipal landfill sites.

Therefore, the case study shows the process of selecting a single or few suitable sites. All retrieved candidate sites were combined based on their normalized weight calculated

Table 5 Criteria used in the present study that matching with other studies on landfill site suitability analysis

Criteria	Sub-criteria/alternatives used in the present study	Kontos et al. (2005)	Chang et al. (2008)	Wang et al. (2009)	Ekmekçioğlu et al. (2010)	Nas et al. (2010)	Şener et al. (2010a, b)	Gbanie et al. (2013)	Şener et al. (2011)	Gorsevski et al. (2012)	Demesouka et al. (2013)
Hydrological Criteria	Surface water	✓		✓	✓		✓	✓	✓	✓	✓
	Wetlands	✓	✓								
	River	✓	✓	✓	✓	✓			✓	✓	
	Canals					✓				✓	
Topographic and climatic criteria	Land elevation		✓	✓	✓		✓	✓	✓	✓	✓
	Land slope		✓	✓	✓	✓	✓	✓	✓	✓	✓
	Surface temperature										✓
	No. of rainy days				✓				✓		✓
Land criteria	Land use land cover	✓	✓		✓			✓		✓	✓
	Geomorphic structure	✓					✓	✓			
	Soil moisture										
	Agricultural land			✓	✓	✓			✓		
Criteria relating accessibility	Major roads		✓	✓		✓	✓	✓	✓	✓	✓
	Railways					✓					✓
	Metro ways										✓
	High ways					✓					✓
Criteria relating infrastructure	Population density							✓		✓	
	Built-up area	✓	✓				✓	✓			✓
	Restricted places	✓		✓		✓	✓				✓
	Sensitive places	✓		✓		✓	✓				✓
No. of citations		250	511	326	187	202	221	140	161	226	79

✓ indicates criteria used in the present study and also in other's study using fuzzy synthetic extent. The applied method allows site suitability using a weighted linear combination and overlays analysis which considered ideal, because assigning criteria weight using mathematical techniques and matrix help in reducing human biases (Gbanie et al. 2013; Moeinaddini et al. 2010). The weighted overly based suitable landfill candidates' sites were finally validated after field investigation. These final candidate sites can be considered for new and back-up municipal sanitary landfill sites for future, because other suitable sites are there within the municipal corporation.

Conclusion

With increasing population and urbanization, the management of municipal solid waste in KMC is becoming great challenges to the municipal authorities, because day-by-day availability of land for waste disposal is decreasing and quantity of solid waste generation is increasing. The recommended GIS-based suitability model discussed in the present study was designed to help the governmental authorities, planners, decisional makers, developers, and civil engineers to locate suitable sites for the municipal landfill to protect communities from ambient air and water contamination, noxious smells, and hazardous smoke from burning of solid waste. In KMC, availability of land is the main problem rather than financial assistance for siting sanitary landfill. Hence, environmental concern and public acceptance were taken as the main criteria in mind during the selection of alternatives. Best landfill candidate sites were selected not only according to environmental consideration and economic factors but also the communities and public acceptance, because waste 'not in my backyard' or 'not in another backyard' is now a rising issue.

The present study offered scientific bases for the study area using multi-criteria-based suitability analysis. The suitable areas for the selection of municipal landfill candidate sites were delineated using the best and common method, i.e., weighted overlay analysis (WOA). GIS has the competence to store, manage, analyze, and display spatial information with combined aspatial information. In this study, the fuzzy analytic hierarchy process (FAHP) as multi-criteria evaluation technique was used for calculating weight and overlay analysis for the potential landfill candidates. The applied technique has the opportunity for adjusting the degree of influence and weight-based level of risk in the decision analysis which offers potential suitability map. This technique was applied to specify areas under potentiality and level of environmental risk that pose upon sitting municipal landfill. Thus, more relevant and interconnected criteria from each aspect were taken as geo-environmental factors which govern landfill siting in term of environmental safety, local aesthetic value, public awareness, and health. This site suitability model offers a chance to planners and developers to rethink about sitting either new or back-up municipal landfill sites.

The present research emphasized the significance of GIS-based techniques in selecting and locating such suitable sites for landfill. This study involved the analysis of enormous spatial and aspatial input data and retrieved output in terms of the degree of suitability for landfill candidates. This study also suggests establishing and applying such techniques for suitability analysis not only for sitting municipal landfill or solving waste management issues but in every field where complex decision support system is required for selecting best alternative for application and interest.

Acknowledgements The authors are highly thankful to municipal authorities (D/O–SWM-I & II, KMC) for providing information and sharing issues regarding new landfill site selection, especially Mr. Subhasish Chattopadhyay, Dy. Ch. Engineer (SWM-I) for a long and healthy discussion regarding that issue. We would also like to thank the local residents of Kolkata Municipal Corporation for their time to discuss and share their own views about landfill site location. We also thankfully acknowledge the anonymous reviewers and Editor-in-Chief for their valuable time, prolific comments, and appreciated suggestions during the review which help in improving the overall quality of the manuscript.

Funding No fund was received from any sources.

Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

References

Adamcová D, Vaverková MD, Barton S, Havlícek Z, Broušková E (2016) Soil contamination in landfills: a case study of a landfill in Czech Republic. Solid Earth 7:239–247. https://doi.org/10.5194/se-7-239-2016

Afzali A, Sabri S, Rashid M, Mohammad Vali Samani J, Ludin ANM (2014) Inter-municipal landfill site selection using analytic network process. Water Resour Manage 28(8):2179–2194

Akbari V, Rajabi MA, Chavoshi SH, Shams R (2008) Landfill site selection by combining GIS and fuzzy multi-criteria decision analysis, case study: Bandar Abbas, Iran. World Appl Sci J 3(1):39–47 https://pdfs.semanticscholar.org/13fd/89645e1532a346a9b6253302b83d6701bb4c.pdf

Ali SA (2016) Status of solid waste generation and management practice in Kolkata municipal corporation, West Bengal. Int J Environ Sci 6(6):1173–1186. https://doi.org/10.6088/ijes.6112

Ali SA, Ahmad A (2019a) Mapping of mosquito-borne diseases in Kolkata Municipal Corporation using GIS and AHP based decision making approach. Spat Inf Res. https://doi.org/10.1007/s41324-019-00242-8

Ali SA, Ahmad A (2019b) Spatial susceptibility analysis of vector-borne diseases in KMC using geospatial technique and MCDM

approach. Model Earth Syst Environ. https://doi.org/10.1007/s40808-019-00586-y
Ali SA, Khatun R, Ahmad A, Ahmad SN (2019) Application of GIS-based analytic hierarchy process and frequency ratio model to food vulnerable mapping and risk area estimation at Sundarban region India. Model Earth Syst Environ. https://doi.org/10.1007/s40808-019-00593-z
Alves MCM, Lima BSLP, Evsukoff AG, Vieira IN (2009) Developing a fuzzy decision support system to determine the location of a landfill site. Waste Manage Res 27(7):641–651. https://doi.org/10.1177/0734242x09103832
Al-Yaqout AF, Hamoda MF (2003) Evaluation of landfill leachate in arid climate—a case study. Environ Intern 29(5):593–600. https://doi.org/10.1016/S0160-4120(03)00018-7
Ayalew L, Yamagishi H, Ugawa N (2004) Landslide susceptibility mapping using GIS-based weighted linear combination, the case in Tsugawa area of Agano River, Niigata Prefecture, Japan. Landslides 1(1):73–81. https://doi.org/10.1007/s10346-003-0006-9
Babalola A, Busu I (2011) Selection of landfill sites for solid waste treatment in Damaturu Town-using GIS techniques. J Environ Prot. https://doi.org/10.4236/jep.2011.21001
Bahrani S, Ebadi T, Ehsani H, Yousefi H, Maknoon R (2016) Modeling landfill site selection by multi-criteria decision making and fuzzy functions in GIS, case study: Shabestar Iran. Environ Earth Sci 75(4):1–14
Balli S, Korukoğlu S (2009) Operating system selection using fuzzy AHP and TOPSIS methods. Math Comput Appl 14(2):119–130
Basharat M, Shah HR, Hameed N (2016) Landslide susceptibility mapping using GIS and weighted overlay method: a case study from NW Himalayas, Pakistan. Arab J Geosci 9:292. https://doi.org/10.1007/s12517-016-2308-y
Belay F, Islam Z, Tilahun A (2015) Application of the overlay weighted model to determine the best locations for expansion of adigrat town. Indo-Afr J Res Manage Plann 3(1):1–9
Beskese A, Demir HH, Ozcan HK, Okten HE (2015) Landfill site selection using fuzzy AHP and fuzzy TOPSIS: a case study for Istanbul. Environ Earth Sci 73:3513–3521. https://doi.org/10.1007/s12665-014-3635-5
Bhambulkar AV (2011) Municipal solid waste collection routes optimized with ArcGIS network analyst. Int J Adv Eng Sci Tech 11(1):202–207
Bhatti SS, Tripathi NK (2014) Built-up area extraction using Landsat 8 OLI imagery. GISci Remote Sens 51(4):445–467. https://doi.org/10.1080/15481603.2014.939539
Boutkhoum O, Hanine M, Agouti T, Tikniouine A (2015) An improved hybrid multi criteria/multidimensional model for strategic industrial location selection: Casablanca industrial zones as a case study. SpringerPlus 4(628):2–23. https://doi.org/10.1186/s40064-015-1404-x
Bozbura F, Beskese A, Kahraman C (2007) Prioritization of human capital measurement indicators using fuzzy AHP. Expert Sys App 32(4):1100–1112
Büyüközkan G, Ruan D (2008) Evaluation of software development projects using a fuzzy multi-criteria decision approach. Math Comput Simul 77(5–6):464–475
Chabuk AJ, Al-Ansari N, Hussain HM, Knutsson S, Pusch R (2017) GIS-based assessment of combined AHP and SAW methods for selecting suitable sites for landfill in Al-Musayiab Qadhaa, Babylon, Iraq. Environ Earth Sci 76:209. https://doi.org/10.1007/s12665-017-6524-x
Chang DY (1996) Applications of the extent analysis method on fuzzy AHP. Eur J Oper Res 95(3):649–655
Chang KT (2018) Introduction to geographic information system, 5th edn. Mc Graw-Hill International Edition, New York. http://dl.booktolearn.com/ebooks2/science/geosciences/9781259929649_Introduction_to_Geographic_Information_Systems_9th_Edition_25de.pdf
Chang N, Parvathinathan G, Breeden JB (2008) Combining GIS with fuzzy multi-criteria decision-making for landfill siting in a fast-growing urban region. J Environ Manage 87:139–153. https://doi.org/10.1016/j.jenvman.2007.01.011
Charnpratheep K, Zhou Q, Garner B (1997) Preliminary landfill site screening using fuzzy geographical information systems. Waste Manage Res 15(2):197–215. https://doi.org/10.1177/0734242x9701500207
Chattopadhyay S, Dutta A, Ray S (2009) Municipal solid waste management in Kolkata, India–a review. Waste Manage 29:1449–1458. https://doi.org/10.1016/j.wasman.2008.08.030
Chen Y, Yu J, Khan S (2010) Spatial sensitivity analysis of multi-criteria weights in GIS-based land suitability evaluation. Environ Model Soft 25(12):1582–1591. https://doi.org/10.1016/j.envsoft.2010.06.001
Chiueh PT, Lo SL, Chang CL (2008) A GIS-based system for allocating municipal solid waste incinerator compensatory fund. Waste Manage 28:2690–2701
Cui J, Zhang L (2008) Metallurgical recovery of metals from electronic waste: a review. J Hazard Mat 158:228–256
Das S, Bhattacharyya BK (2015) Optimization of municipal solid waste collection and transportation routes. Waste Manage 43:9–18. https://doi.org/10.1016/j.wasman.2015.06.033
Delgado OB, Mendoza M, Granados EL, Geneletti D (2008) Analysis of land suitability for the siting of inter-municipal landfills in the Cuitzeo Lake Basin. Mexico Waste Manage 28(7):1137–1146. https://doi.org/10.1016/j.wasman.2007.07.002
Demesouka OE, Vavatsikos AP, Anagnostopoulos KP (2013) Suitability analysis for siting MSW landfills and its multicriteria spatial decision support system: method, implementation and case study. Waste Manage 33(5):1190–1206. https://doi.org/10.1016/j.wasman.2013.01.030
Dhokhikah Y, Trihadiningrum Y (2012) SolidWaste management in Asian developing countries: challenges and opportunities. J App Environ Biol Sci 2:329–335
Donevska KR, Gorsevski PV, Jovanovski M, Pesevski I (2011) Regional non-hazardous landfill site selection by integrating fuzzy logic, AHP and geographic information systems. Environ Earth Sci 67(1):121–131. https://doi.org/10.1007/s12665-011-1485-y
Ebistu AT, Minale AS (2013) Solid waste dumping site suitability analysis using geographic information system (GIS) and remote sensing for Bahir Dar Town, North Western Ethiopia. Afr J Environ Sci Tech 7(11):976–989. https://doi.org/10.5897/AJEST2013.1589
Efe B (2016) An integrated fuzzy multi criteria group decision making approach for ERP system selection. Appl Soft Comput 38:106–117
Ekmekçioğlu M, Kaya T, Kahraman C (2010) Fuzzy multicriteria disposal method and site selection for municipal solid waste. Waste Manage 30(8–9):1729–1736. https://doi.org/10.1016/j.wasman.2010.02.031
El Baba M, Kayastha P, De Smedt F (2015) Landfill site selection using multi-criteria evaluation in the GIS interface: a case study from the Gaza Strip, Palestine. Arab J Geosci 8(9):7499–7513
Eskandari M, Homaee M, Falamaki A (2016) Landfill site selection for municipal solid wastes in mountainous areas with landslide susceptibility. Environ Sci Pollut Res 23(12):12423–12434. https://doi.org/10.1007/s11356-016-6459-x
Feizizadeh B, Blaschke T (2013) GIS-multicriteria decision analysis for landslide susceptibility mapping: comparing three methods for the Urmia lake basin, Iran. Nat Hazards 65:2105–2128

Feo GD, Gisi SD (2014) Using MCDA and GIS for hazardous waste landfill siting considering land scarcity for waste disposal. Waste Manage 34(11):2225–2238

Gbanie SP, Tengbe PB, Momoh JS, Medo J, Kabba VTS (2013) Modelling landfill location using Geographic Information Systems (GIS) and Multi-Criteria Decision Analysis (MCDA): Case study Bo, Southern Sierra Leone. App Geog 36:3–12. https://doi.org/10.1016/j.apgeog.2012.06.013

Gemitzi A, Tsihrintzis VA, Voudrias E, Petalas C, Stravodimos G (2006) Combining geographic information system, multi-criteria evaluation techniques and fuzzy logic in sitting MSW landfills. Environ Geol 51(5):797–811. https://doi.org/10.1007/s00254-006-0359-1

Gorsevski PV, Donevska KR, Mitrovski CD, Frizado JP (2012) Integrating multi-criteria evaluation techniques with geographic information systems for landfill site selection: a case study using ordered weighted average. Waste Manage 32:287–296. https://doi.org/10.1016/j.wasman.2011.09.023

Ground water information booklet (2007) Kolkata Municipal Corporation, West Bengal. http://cgwb.gov.in/District_Profile/WestBangal/Kolkata%20Municipal%20Corporation.pdf. Accessed 5 Apr 2019

Guerrero LA, Maas G, Hogland W (2013) Solid waste management challenges for cities in developing countries. Waste Manage 33:220–232. https://doi.org/10.1016/j.wasman.2012.09.008

Guiqin W, Li Q, Guoxue L, Lijun C (2009) Landfill site selection using spatial information technologies and AHP: a case study in Beijing, China. J Environ Manage 90(8):2414–2421. https://doi.org/10.1016/j.jenvman.2008.12.008

Guler D, Yomralioglu T (2017) Alternative suitable landfill site selection using analytic hierarchy process and geographic information systems: a case study in Istanbul. Environ Earth Sci 76:678. https://doi.org/10.1007/s12665-017-7039-1

Gworek B, Dmuchowski W, Gozdowski D, Koda E, Osiecka R, Borzyszkowski J (2015) Influence of a municipal waste landfill on the spatial distribution of mercury in the environment. PLoS ONE 10(7):e0133130. https://doi.org/10.1371/journal.pone.0133130

Hanine M, Boutkhoum O, Tikniouine A, Tarik Agouti T (2016) Comparison of fuzzy AHP and fuzzy TODIM methods for landfill location selection. SpringerPlus 5:501. https://doi.org/10.1186/s40064-016-2131-7

Hasan SE (2004) Public awareness is key to successful waste management. J Environ Sci Health Part A 39(2):483–492. https://doi.org/10.1081/ese-120027539

Hazra T, Goel S (2009) Solid waste management in Kolkata, India: practices and challenges. Waste Manage 29:470–478

Jamil M, Sahana M, Sajjad H (2018) Crop suitability analysis in the Bijnor District, UP, using geospatial tools and fuzzy analytical hierarchy process. Agric Res 7(4):506–522. https://doi.org/10.1007/s40003-018-0335-5

Jaybhaye R, Mundhe N, Dorik B (2014) Site suitability for urban solid waste disposal using geoinformatics: a case study of Pune municipal corporation, Maharashtra, India. Int J Adv Remote Sens GIS 3(1):769–783. https://technical.cloud-journals.com/index.php/IJARSG/article/view/Tech-317

Kaliraj S, Chandrasekar N, Magesh NS (2015) Evaluation of multiple environmental factors for site-specific groundwater recharge structures in the Vaigai River upper basin, Tamil Nadu, India, using GIS-based weighted overlay analysis. Environ Earth Sci 74:4355–4380. https://doi.org/10.1007/s12665-015-4384-9

Kao JJ, Lin HY (1996) Multifactor spatial analysis for landfill siting. J Environ Eng 122(10):902–908. https://doi.org/10.1061/(asce)0733-9372(1996)122:10(902)

Khan D, Samadder SR (2015) A simplified multi-criteria evaluation model for landfill site ranking and selection based on AHP and GIS. J Environ Eng Lands Manage 23(4):267–278

Kharat MG, Kamble SJ, RauTRD KSS, Dhume SM (2016) Modeling landfill site selection using an integrated fuzzy MCDM approach. Model Earth Syst Environ 2:53. https://doi.org/10.1007/s40808-016-0106-x

Khorram A, Yousefi M, Alavi SA, Farsi J (2015) Convenient landfill site selection by using fuzzy logic and geographic information systems: a case study in Bardaskan East of Iran. Health Scope 4(1):e19383. https://doi.org/10.17795/jhealthscope-19383

Knox E (2000) Childhood cancers, birthplaces, incinerators and landfill sites. Int J Epidemiol 29(3):391–397. https://doi.org/10.1093/ije/29.3.391

Kontos TD, Komilis DP, Halvadakis CP (2003) Siting MSW landfills on Lesvos Island with a GIS based methodology. Waste Manage Res 21:262–277

Kontos TD, Komilis DP, Halvadakis CP (2005) Siting MSW landfills with a spatial multiple criteria analysis methodology. Waste Manage 25(8):818–832. https://doi.org/10.1016/j.wasman.2005.04.002

Leao S, Bishop I, Evans D (2001) Spatial-temporal model for demand and allocation of waste landfills in growing urban regions. Comput Environ Urban Syst 28:353–385

Lima Junior FR, Osiro L, Carpinetti LCR (2014) A comparison between fuzzy AHP and Fuzzy TOPSIS methods to supplier selection. App Soft Comput 21:194–209

Lober DJ (1995) Resolving the siting impasse: modeling social and environmental locational criteria with geographic information system. Am Plan Assoc 61(4):482–495. https://doi.org/10.1080/01944369508975659

Long YY, Shen DS, Wang HT, Lu WJ, Zhao Y (2011) Heavy metal source analysis in municipal solid waste (MSW): case study on Cu and Zn. J Hazard Mat 186:1082–1087

Lukasheh AF, Droste RL, Warith MA (2001) Review of expert system (ES), geographical information system (GIS), decision support system (DSS) and their application in landfill design and management. Waste Manage Res 19(2):177–185. https://doi.org/10.1177/0734242x0101900209

Mahini SA, Gholamafard M (2006) Siting MSW landfills with a weighted linear combination methodology in a GIS environment. Int J Environ Sci Tech 3(4):435–445. https://doi.org/10.1007/bf03325953

Malczewski J (2006) GIS-based multicriteria decision analysis: a survey of the literature. Int J Geog Inform Sci 20(7):703–726. https://doi.org/10.1080/13658810600661508

Minichilli F, Bartolacci S, Buiatti E, Pallante V, Scala D, Bianchi F (2005) A study on mortality around six municipal solid waste landfills in Tuscany Region. Epidemiol Prevenzione 29(suppl 5–6):53–56

Minichilli F, Bartolacci S, Buiatti E, Pierini A, Rossi G, Bianchi F (2006) An update of mortality in a high environmental risk area of Tuscany Region (Italy). Epidemiology 17(Suppl):S260–S261. https://doi.org/10.1097/00001648-200611001-00675

Moeinaddini M, Khorasani N, Danehkar A, Darvishsefat AA, Zienalyan M (2010) Siting MSW landfill using weighted linear combination and analytical hierarchy process (AHP) methodology in GIS environment (case study: Karaj). Waste Manage 30(5):912–920. https://doi.org/10.1016/j.wasman.2010.01.015

Moghaddas NH, Namaghi HH (2009) Hazardous waste landfill site selection in Khorasan Razavi Province Northeastern Iran. Arab J Geosci 4(1e2):103e113

Mojiri A, Aziz HA, Zaman NQ, Aziz SQ, Zahed MA (2014) Powdered ZELIAC augmented sequencing batch reactors (SBR) process for co-treatment of landfill leachate and

domestic wastewater. J Environ Manage 139:1–14. https://doi.org/10.1016/j.jenvman.2014.02.017
Nas B, Cay T, Iscan F, Berktay A (2010) Selection of MSW landfill site for Konya, Turkey using GIS and multi-criteria evaluation. Environ Monit Assess 160(1–4):491–500. https://doi.org/10.1007/s10661-008-0713-8
Onut S, Soner S (2008) Transshipment site selection using the AHP and TOPSIS approaches under fuzzy environment. Waste Manage 28(9):1552–1559. https://doi.org/10.1016/j.wasman.2007.05.019
Ouma YO, Kipkorir EC, Tateishi R (2011) MCDA-GIS integrated approach for optimized landfill site selection for growing urban regions: an application of neighborhood-proximity analysis. Annal GIS 17(1):43–62. https://doi.org/10.1080/19475683.2011.558021
Parida BR, Collado WB, Borah R, Hazarika MK, Samarakoon L (2008) Detecting drought-prone areas of rice agriculture using a MODIS-derived soil moisture index. GISci Remote Sens 45(1):109–129. https://doi.org/10.2747/1548-1603.45.1.109
Pathak A, Dastidar MG, Sreekrishnan TR (2009) Bioleaching of heavy metals from sewage sludge: a review. J Environ Manage 90:2343–2353
Paul S (2012) Location allocation for urban waste disposal site using multi-criteria analysis: a study on Nabadwip Municipality, West Bengal, India. Int J Geomat Geosci 3(1):74–87. www.ipublishing.co.in/jggsvol1no12010/volthree/EIJGGS3107.pdf
Porta D, Milani S, Lazzarino AI, Perucci CA, Forastiere F (2009) Systematic review of epidemiological studies on health effects associated with management of solid waste. Environ Health 8(60):1–14. https://doi.org/10.1186/1476-069X-8-60
Rafiee R, Khorasani N, Mahiny AS, Darvishsefat AA, Danekar A, Hasan SE (2011) Siting transfer stations for municipal solid waste using a spatial multi-criteria analysis. Environ Eng Geosci 17(2):143–154. https://doi.org/10.2113/gseegeosci.17.2.143
Rahman MM, Sultana KR, Hoque MA (2008) Suitable sites for urban solid waste disposal using GIS approach in Khulna city Bangladesh. Proc Pak Acad Sci 45(1):1122
Riad PHS, Billib M, Hassan AA, Salam MA, Nour El Din M (2011) Application of the overlay weighted model and boolean logic to determine the best locations for artificial recharge of groundwater. J Urban Environ Eng 5(2):57–66. https://doi.org/10.4090/juee.2011.v5n2.057066
Roslee R, Mickey AC, Simon N, Norhisham MN (2017) Landslide susceptibility analysis (Lsa) using weighted overlay method (Wom) along the Genting Sempah to Bentong Highway, Pahang. Malays J Geosci 1(2):13–19
Rushton L (2003) Health hazards and waste management. Br Med Bull 68:183–197. https://doi.org/10.1093/bmb/ldg034
Russi MB, Borak JB, Cullen MR (2008) An examination of cancer epidemiology studies among populations living close to toxic waste sites. Environ Health 7(1):7–32. https://doi.org/10.1186/1476-069x-7-32
Şener Ş, Şener E, Nas B, Karagüzel R (2010a) Combining AHP with GIS for landfill site selection: a case study in the Lake Beyşehir catchment area (Konya, Turkey). Waste Manage 30(11):2037–2046. https://doi.org/10.1016/j.wasman.2010.05.024
Şener Ş, Şener E, Nas B, Karagüzel R (2010b) Combining AHP with GIS for landfill site selection: a case study in the Lake Beyşehir catchment area (Konya, Turkey). Waste Manage 30(11):2037–2046
Sener S, Sener E, Karagüzel R (2011) Solid waste disposal site selection with GIS and AHP methodology: a case study in Senirkent-Uluborlu (Isparta) Basin, Turkey. Environ Monit Assess 173:533–554. https://doi.org/10.1007/s10661-010-1403-x
Setianto A, Triandini T (2013) Comparison of kriging and inverse distance weighted (IDW) interpolation methods in lineament extraction and analysis. J SE Asian Appl Geol 5(1):21–29
Sharifi M, Hadidi M, Vessali E, Mosstafakhani P, Taheri K, Shahoie S, Khodamoradpour M (2009) Integrating multi-criteria decision analysis for a GIS-based hazardous waste landfill sitting in Kurdistan Province, western Iran. Waste Manage 29(10):2740–2758. https://doi.org/10.1016/j.wasman.2009.04.010
Tavares G, Zsigraiova Z, Semiao V (2011) Multi-criteria GIS-based siting of an incineration plant for municipal solid waste. Waste Manage 31(9–10):1960–1972. https://doi.org/10.1016/j.wasman.2011.04.013
Torabi-Kaveh M, Babazadeh R, Mohammadi SD, Zaresefat M (2016) Landfill site selection using combination of GIS and fuzzy AHP, a case study: Iranshahr Iran. Waste Manage Res. https://doi.org/10.1177/0734242X16633777
Troschinetz AM, Mihelcic JR (2009) Sustainable recycling of municipal solid waste in developing countries. Waste Manage 29:915–923. https://doi.org/10.1016/j.wasman.2008.04.016
Udomporn C, Wanpen W, Punya C, William M, Rungruang L (2009) Landfill site characterization Kham Bon village, Muang district, Khon Kaen province, NE Thailand. Int J Environ Waste Manage 4(2–3):299–321. https://doi.org/10.1504/ijewm.2009.027398
Upton AC (1989) Public health aspects of toxic chemical disposal sites. Ann Rev Public Health 10:1–25
Vahidnia MH, Alesheikh AA, Alimohammadi A (2009) Hospital site selection using fuzzy AHP and its derivatives. J Environ Manage 90(10):3048–3056. https://doi.org/10.1016/j.jenvman.2009.04.010
Vrijheid M (2000) Health effects of residence near hazardous waste landfill sites: a review of epidemiologic literature. Environ Health Perspec 108:101–112
Wang YM, Chin KS (2011) Fuzzy analytic hierarchy process: a logarithmic fuzzy preference programming methodology. Int J Approx Reas 52:541–553. https://doi.org/10.1016/j.ijar.2010.12.004
Wang L, Qu JJ (2009) Satellite remote sensing applications for surface soil moisture monitoring: a review. Front Earth Sci China 3(2):237–247. https://doi.org/10.1007/s11707-009-0023-7
Wang G, Qin L, Li G, Chen L (2009) Landfill site selection using spatial information technologies and AHP: a case study in Beijing, China. J Environ Manage 90(8):2414–2421. https://doi.org/10.1016/j.jenvman.2008.12.008
Witlox F (2005) Expert systems in land-use planning: an overview. Expert Sys Appl 29:437–445
Xu H (2007) Extraction of urban built-up land features from landsat imagery using a thematic-oriented index combination technique. Photogr Eng Remote Sens 73(12):1381–1391. https://doi.org/10.14358/pers.73.12.1381
Yang L, Chen Z, Liu T, Gong Z, Yu Y, Wang J (2013) Global trends of solid waste research from 1997 to 2011 by using bibliometric analysis. Scientometrics 96:133–146. https://doi.org/10.1007/s11192-012-0911-6
Yesilnacar MI, Cetin H (2005) Site selection for hazardous wastes: a case study from the GAP area, Turkey. Eng Geol 81(4):371–388. https://doi.org/10.1016/j.enggeo.2005.07.012
Yesilnacar MI, Cetin H (2008) An environmental geomorphologic approach to site selection for hazardous wastes. Environ Geol 55(8):1659–1671. https://doi.org/10.1007/s00254-007-1115-x
Yu X, Guo X, Wu Z (2014) Land surface temperature retrieval from landsat 8 TIRS—comparison between radiative transfer equation-based method, split window algorithm and single channel method. Remote Sens 6:9829–9852. https://doi.org/10.3390/rs6109829

Zamorano M, Molero E, Hurtado A, Grindlay A, Ramos A (2008) Evaluation of a municipal landfill site in Southern Spain with GIS-aided methodology. J Hazard Mat 160:473–481

ZelenovićVasiljević T, Srdjević Z, Bajčetić R, VojinovićMiloradov M (2011) GIS and the analytic hierarchy process for regional landfill site selection in transitional countries: a case study from Serbia. Environ Manage 49(2):445–458

Zeng Y, Feng Z, Xiang N (2004) Assessment of soil moisture using Landsat ETM+ temperature/vegetation index in semiarid environment. In: Geoscience and Remote Sensing Symposium, IGARSS '04. Proceedings. 2004 IEEE International, vol 6, pp 4306–4309. https://doi.org/10.1109/IGARSS.2004.1370089

Zucca A, Sharifi AM, Fabbri AG (2008) Application of spatial multi-criteria analysis to site selection for a local park: a case study in the Bergamo Province, Italy. J Environ Manage 88:752–769