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Potential landfill sites selection using GIS-based multi-criteria decision analysis in Dodoma capital city, central Tanzania

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Abstract Solid waste management is a global challenge, especially in developing countries due to the rapid increase in population and urbanization where the availability of sanitary landfills is inevitable. Determining suitable landfill sites is a fundamental aspect for new and rapidly growing cities. The current study is aimed at selecting potential landfill sites using GIS-based multi-criteria decision analysis in Dodoma capital city. Fifteen criteria including proximity from built-up areas, surface water, boreholes, sensitive sites including social service areas, episodic water channels, protected areas including historical sites, faults, land use/land cover, geology, soil type, elevation, slopes, airport, roads, and earthquake epicentres were integrated with the help of analytical hierarchy process (AHP). The landfill sites' suitability map was produced based on the weighted linear combination method and assigned suitability classes as highly suitable, suitable, moderately suitable, less suitable, and unsuitable. The overall suitability results show that 41,177 ha (14.7%) of the study area is determined as highly suitable for landfills site location. The remaining 83,930 ha (30%), 84,305 ha (30.2%), and 53,508 ha (19.1%) of the area are suitable, moderately suitable, and less suitable respectively while 16,683 ha (6%) is under the unsuitable zone. From the highly suitable area, eleven candidate landfill sites were selected and prioritized using the AHP technique. The final results show landfill site 3 (10,361.94 ha), 5 (3717.85 ha), and 2 (3535.86 ha) were found to be the most highly suitable sites with eigenvector weight of 0.147, 0.122, and 0.121 respectively. Landfill sites 8, 7, and 6 were lastly considered. Field observation involving expertise from geology, hydrogeology, geophysical, and environment confirmed the suitability of selected sites. Thus, these techniques can be employed in developing countries to locate suitable landfill sites to minimize health and environmental impacts.

Keywords AHP · GIS · Landfills · Dodoma capital city

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Introduction

Waste is any useless material produced from human activities, which results in adverse impacts on human health and the environment (Mussa & Suryabhagavan, 2019; Taye, 2018). Waste is categorized as solid and liquid (Azevedo et al., 2019). Solid wastes include non-liquid and non-gaseous products discharged from households, hospitals, restaurants, industries, markets, institutions, and construction areas (Kapilan & Elangovan, 2018; Singh, 2019). Solid waste is a global threat both in developing and developed countries (Abarca-Guerrero et al., 2015; UNEP, 2005) however, the situation is worse in low-income countries (Nakada et al., 2006). Solid waste management practices of landfilling used by many countries have recently shifted to incineration (Lino & Ismail, 2017; Mussa & Suryabhagavan, 2019; Rezaei et al., 2018) but still landfilling remain the best solid waste management practice (Balew et al., 2020; Ohri et al., 2015), and is the oldest common method of solid waste disposal (Weldeyohanis et al., 2020). Recently, there are notable efforts worldwide towards the establishment and designing of landfills to increase environmental protection (Stamps et al., 2016; Wilson et al., 2015). Poor collection of waste, recycling, and uncontrolled dumping results in human and environmental problems (Duve et al., 2015), and may cause contamination of surface and groundwater through leachate, direct contact with surface water, air pollution, land pollution, and associated health impacts on communities (Rikta et al., 2018). Also, various studies indicate the presence of heavy metals in leachate which may lead to death (Rikta et al., 2018; Roumak et al., 2018). Therefore, amongst many reasons, proper landfill sites selection is inevitable in growing cities and towns worldwide (Abedi-Varaki & Davtalab, 2016; Ajibade et al., 2019; Ebistu & Minale, 2013; Khorsandi et al., 2019).

In developing countries, most landfill sites are not scientifically located (Balew et al., 2020), and solid waste management practices are inappropriate due to lack of early planning, technology hindrance, economic barriers (Harerimana et al., 2016), poor infrastructure, and bureaucratic among others that impede the waste management strategies (Hoornweg & Bhada-Tata, 2012). Most countries use open dumpsites without leachate and gas management (Ebistu & Minale, 2013; Gizachew, 2011), which eventually affects the environment and quality of life. In Africa, it is estimated that the solid waste production rate ranges from 1.2 to 1.42 kg per person daily (Hoornweg et al., 2013). In Tanzania, the dusting of solid waste in informal open dumpsite threatens human health and the environment (Huisman et al., 2016; Yhdego, 2017). Several studies on solid waste management have been carried out within the country including (Huisman et al., 2016; Kazuva et al., 2020; Yhdego, 2017) and in Dodoma city (Katura, 2013; Mussa, 2015; Nyampundu et al., 2020) on improved solid waste management practises and (Lyimo et al., 2020) involving spatial aspects. The current study assimilates an extensive coverage including Dodoma city and some parts of Chamwino district which host essential central government and other agencies' offices, fifteen influencing criteria are incorporated to increase the chances of attaining the most suitable landfill sites and prioritize determined sites basing on their sizes and distances from residential areas to scale down the uncertainty of choosing the most highly suitable site which is still indefinite. It is estimated that a total of 350 tonnes of solid wastes are produced daily from different sources within the city including 208 tonnes from residential areas, 30 tonnes from institutions, 30 tonnes from the markets, 35 tonnes from industries, 32 tonnes from commercial areas, and 15 tonnes from other sources (URT, 2018, 2020). Owing to inappropriate solid waste management practices within the capital city, limited solid waste hauling trucks, and waste collection containers, most waste dumping sites are any unsuitable open grounds, roadsides, valleys, and seasonal waterways (episodic water channels) which may result in significant effects to environments, human health, and quality of urban life (CCD, 2020; Mussa, 2015). The poor sanitary situation is a common face to many streets within the city including Majengo, Sango, Sabasaba, Nzuguni, Msalato, Bonanza, Veyula, and Dodoma-Makulu. Dodoma capital city was merely selected due to its significance within the country as the capital city, and in recent, it is the fastest-growing city in Tanzania due to the shift of all government offices to the capital city (Msabi & Makonyo, 2020; Xinhua, 2018). This has resulted in a tremendous increase in population within the city which requires environmentally sound development to control the existing pressure of wastes production.

Geographical Information System (GIS) and Remote Sensing (RS) technologies are extensively integrated into spatial problem solving due to their time and cost-effectiveness as well as providing reliable digital data inventory for effective monitoring of resources (Hwang & Lin, 2012; Mussa & Suryabhagavan, 2019; Tehrany et al., 2017). RS plays a vital role in providing spatial thematic information including LULC, drainage, slopes, elevations, among others

(Emun, 2010; Mussa & Suryabhagavan, 2019). Similarly, multi-criteria decision analysis (MCDA) based on Analytical Hierarchy Process (AHP) technique is extensively engaged to combine socio-economic, environmental, and technical aspects in analysing complex spatial related problems involving conflicting criteria (Adewumi et al., 2019; Ghanbarpour et al., 2013; Hwang & Lin, 2012) and is revealed as the most appropriate method for site selection (Coban et al., 2018; Ersoy & Bulut, 2009; Mutluturk & Karaguzel, 2007; Şener et al., 2010; Simsek et al., 2006; Yesilnacar & Cetin, 2008). The integration of GIS and the AHP technique has been a more powerful instrument to solve landfill selection problems (Allen et al., 2003; Şener et al., 2006). In the current study, AHP has been employed. This technique enables the decision-maker to employ various preferences (Saaty, 1980). Many researchers in solid waste site selection worldwide indicate that decision-making criteria globally follow the same objectives: environmental, economic, and social desirability (Balew et al., 2020; Mussa & Suryabhagavan, 2019; Panepinto & Zanetti, 2018). GIS-based MCDA has been used for solid waste dumping site selection worldwide (Ajibade et al., 2019; Balew et al., 2020; Rahimi et al., 2020; Sisay et al., 2020; Yousefi et al., 2018) and in Tanzania (Kazuva et al., 2020).

The selection of suitable landfill sites is a complex process that requires expertise from various disciplines including geology, environmental, urban planning, soil, and hydrology (Alanbari et al., 2014; Yadav, 2013; Yesilnacar & Cetin, 2005). On the other hand, researchers have integrated various influencing criteria in siting landfills including economic and land suitability parameters (Delgado et al., 2008), public preferences and social costs (Guikema, 2005), distance from waste generation sources, predominant land use type, the slope of the area, and groundwater depth (Nas et al., 2010), economic, environmental cost, soil type, restricted areas, proximity from roads (Wang et al., 2009), road networks, conserved areas, ease of operation, safety (Bagdanavičiūtė & Valiūnas, 2013; Sumathi et al., 2008). But different criteria apply in different areas (Babalola & Busu, 2011; Sadek et al., 2006). The use of wide-ranging influencing criteria increases the chances of attaining the most suitable choice (Ersoy & Bulut, 2009; Gorsevski et al., 2012; Kharat et al., 2016). In the current study, fifteen influencing factors were employed including proximity from built-up area, surface water, episodic water channels, boreholes, sensitive sites, protected areas, faults, airport, roads & railway, and earthquake epicentres, LULC, geology, soil type, elevation and slopes in an appropriate combination. Therefore, this study is aimed at selecting potential landfill sites using GIS-based MCDA in Dodoma capital city. The findings of the current study, will help the capital city planners, decision-makers, and concerned stakeholders to improve solid waste management practises within the capital city, provide methodological framework to solve the challenges of locating landfills and asses if the existing landfill meets the required siting criteria.

Literature review

Solid waste management practices worldwide

Solid waste is becoming a global threat, especially in low-income countries causing environmental, health, social, and economic effects (Iyamu et al., 2020; Kokkinos et al., 2019; Oguntoke et al., 2019). An increase in population, urbanization, and industrialization triggers the production of waste in most cities and worldwide (Weldeyohanis et al., 2020; Xiao et al., 2020), with great effects on the environment and human health observed in most developing countries (Zhou et al., 2019). It is estimated that about 3 billion of the world population have scarcity to proper waste disposing facilities such as landfills with other disposing alternatives under investigations (Wilson et al., 2015). Poor planning of cities, population inflation, expansion of urban areas, higher living standards among others results in improper waste management in most low-income countries (Al-Salem et al., 2018; Ghinea et al., 2016); resulting in degradation of the earth's resources and quality of life (Carota et al., 2018). In the recent world, 1.3 billion tonnes of solid waste are produced yearly (Orhorhoro & Oghoghorie, 2019), with the expectation of 2.2 billion tonnes by 2025 (Kharlamova et al., 2016). In African countries, about 95% of solid waste produced from different sources is discarded at peripheries of cities or in open dumpsites and wetland areas (Weldeyohanis et al., 2020). Thus, proper management of solid waste is of vital importance for human prosperity (Srivastava, 2020). Landfilling is the least and the final preferred method in the waste management hierarchy and a popular method of waste disposal. Open waste dumping being a common practice in most low-income countries due to poor waste management services (Weldeyohanis et al., 2020). Selecting of suitable sites for landfills placement is among the complicated process in solid waste management (Weldeyohanis et al., 2020); which must disclose social, environmental, economic and technical aspects (El-Kelani et al., 2017). Landfilling involves the process of receiving waste, compaction, waste placement, and setting up of landfill control equipment (Dahal & Adhikari, 2018). Finally, landfills should be properly designed and operated to reduce environmental, socio-economic, and health impacts.

Application of GIS-based MCDA in landfill sites selection

Geographic information system

GIS is a computerized tool and framework for capturing, storing, retrieving, updating, manipulating, displaying, mapping and analysing the spatial relationship between mapped geographical aspects on the earth's surface (Rikalovic et al., 2014). Spatial datasets analysed in GIS can be applied in planning and managing natural and socio-economic environments (Balew et al., 2020). Also enables the policymakers to link unrelated sources of information, analyse, visualize trend, and organize long term planning objectives for better decision making (Malczewski, 2004). This provides a conceptual spatial framework to support the decision for the best management of the earth's resources and human setting. Furthermore, it also provides spatial database operations such as geostatistical operation, query functions, analysis and modelling. GIS has the capability of showing effective spatial–temporal changes of an area (Ajibade et al., 2019; Dar et al., 2019; Soroudi et al., 2018). This technology is widely used due to its capability in spatial problem solving including landfill sites selection, groundwater exploration, mineral exploration, drought monitoring, flooding mapping, foretelling spatial challenges, and providing an alternative solution to spatial challenges. Hence, it is a supportive tool in spatial decision-making (Malczewski, 1999). In landfill sites selection studies, GIS is mostly applied in the preparation of various datasets including slopes, drainage density, elevations, and used for computation of proximity distances, overlaying the datasets and analysing the results (Rikalovic et al., 2014), planning and monitoring of waste transport routes, site management, and visualizing (Sumathi et al., 2008; Wang et al., 2009) as well as preparing the landfill sites suitability map of the study area.

Multi-criteria decision analysis

MCDA is an assessment technique that enables the ranking of numerous likely options by locating various evaluation criteria with conflicting goals (Balew et al., 2020). The approach has the following components: decision-makers, assessment criteria, options, and decision output (Malczewski, 1999). MCDA involves a series of approaches including a weighted sum that enables a range of contributing criteria related to any spatial challenge to be scored, evaluated, weighted, and ranked based on their contributing suitability (Malczewski, 1999, 2006). The MCDA methods are widely employed to combine socio-economic, environmental, and technical criteria for efficient decision-making involving any particular spatial problem on the earth's surface (Mohebbi et al., 2013). MCDA consists of various methods of evaluating spatial challenge however, AHP and WLC techniques are widely used in various suitability studies. A number of studies worldwide involving AHP multi-criteria in the evaluation of the spatial decision include (Alkaradaghi et al., 2019; Das & Pal, 2020; Kumari & Pandey, 2020; Ruiz et al., 2020) and studies involving the WLC method (Coscrato et al., 2020; Dereli & Tercan, 2020; Msabi & Makonyo, 2020; Yin et al., 2020) and GIS-based for landfill sites selection (Chabok et al., 2020; Karakuş et al., 2020; Özkan et al., 2020; Tercan et al., 2020). Therefore, the MCDA technique is widely accepted for analysing complex decision problems involving criteria with conflicting objectives (Hwang & Lin, 2012; Malczewski, 2006).

Analytic hierarchy process

AHP is amongst the popular used MCDA methods which rely on the expert's knowledge in assigning weights and enables the reflection of objective and subjective criteria in the ranking of the alternatives (Saaty, 1980). It is a scientific technique that analyses complex spatial problems with multiple involving criteria (Adewumi et al., 2019; Chen et al., 2009). However, the techniques are incapable of determining the uncertainties accumulated in the ranking of the criteria (Bathrellos et al., 2013) but remain the appropriate method for site selection problems (Das & Pardeshi, 2018; Raviraj et al., 2017; Selvam et al., 2016) and regional studies (Rozos et al., 2011; Subramanian & Ramanathan, 2012). This technique enables the decision-maker to decompose the criteria and alternative solutions of the spatial problem into a hierarchical structural (Eldrandaly et al., 2005; Saaty & Vargas, 2012). AHP is a flexible and powerful tool for producing factors' weights according to the built pairwise comparison matrix of the criteria (Balew et al., 2020). Thus, the higher the weight the most important is the criteria (Malczewski, 2006). The AHP technique follows the following three steps: (1) decomposing a problem into a hierarchy structure (2) comparing the decision elements in which a pairwise comparison matrix is built (3) computing normalized eigenvector which determines the criteria's weights and computation of the consistency ratio of the involved elements (Malczewski, 1999; Saaty & Vargas, 2012).

Weighted linear combination

WLC is one of the multi-criteria techniques equipped with the conception of fuzzy theory (Balew et al., 2020) and is used in GIS environments to scrutinize site selection problems (Khorsandi et al., 2019; Yousefi et al., 2018). The method enables the decision-maker to allocate criteria weight based on their influence as well as combining the reclassified influencing factors to obtain the final suitability map (Malczewski, 2004). WLC technique based on MCDA follows six steps: (1) itemizing set of influencing criteria and alternatives, (2) standardizing the set criteria, (3) defining criteria's weights, (4) creating standardized weighted thematic maps, (5) producing the final score, and (6) ranking the alternatives (Malczewski, 1999). Furthermore, the WLC is employed in evaluating the uncertainties in a wide range of alternatives in site selection spatial problems (Higgs, 2006).

GIS-based MCDA

GIS-based MCDA is a decision-making process in which geographically referenced datasets and significant judgment values are combined to obtain more valuable facts for spatial decision-making (Malczewski, 2006). Spatial MCDA consists of the use of geo-referenced datasets, decision maker's choices, integration of the thematic datasets, and choices as per defined decision procedures (Malczewski, 2006). Spatial decision-making involving conflicting criteria is quite challenging in the selection of the best choice (Rikalovic et al., 2014). Though, it can be easily resolved by spatial-based MCDA (Balew et al., 2020). Spatial-based multi-criteria problems have geographical clear alternatives and are normally influenced by the set of evaluation criteria (Jankowski, 1995; Malczewski, 1996). GIS technology is widely employed in landfills sites selection and provides associated information for each evaluated site (Jiang & Eastman, 2000). Conversely, the MCDA method provides a wide range of evaluation techniques and methodologies that are assimilated in GIS and enable to conceal decision maker's choices in the spatial decision (Eldrandaly et al., 2005; Malczewski, 2006). Landfills sites selection is a complex process that involves set of conflicting factors from different discipline including geology, hydrogeology, socio-economic, environmental among others (Eldrandaly et al., 2005), which are easily evaluated by MCDA incorporating with GIS technique (Alkaradaghi et al., 2019; Malczewski, 2004). GIS-based MCDA is essential in the evaluation of a set of alternatives involving conflicting criteria (Balew et al., 2020) thus, helpful in solving site selection spatial problems (Laskar, 2003) and is proved as the best method in landfill site selection (Alkaradaghi et al., 2019). In landfill site selection GIS-based MCDA involves the following steps: (1) itemization of a set of influencing criteria, (2) standardizing the set criteria, (3) assigning criteria weights, and (4) integrating evaluated criteria's weights using the WLC method. Finally, landfill sites' suitability map is produced by the combination of the criteria's weights and the evaluated criteria (Hasan et al., 2009), which is also easily ranked based on their suitability (Balew et al., 2020). Furthermore, GIS-based MCDA techniques are cost and time effective in site selection problems (Bhushan & Rai, 2007; Mussa & Suryabhagavan, 2019).

Description of the study area

The capital city is located in Dodoma region, the central part of Tanzania. It is boarded in the East by Chamwino district and in the West by Bahi district, it is situated 453 km away from Dar es Salaam the former capital city of Tanzania, and 441 km south of Arusha, the head-quarter of the East African Community (EAC). The capital city includes Dodoma city and some parts of Chamwino districts covering an area of about 279,606.1 ha (Fig. 1) of which 62,500 ha is urbanized (CCD, 2020). Demographically, according to the Tanzania National Bureau of Statistics (NBS), the 2012 Census indicates that the capital city has a total of 410,956 inhabitants of which 199,487 people (48.5%) are male while 211,469 people (51.5%) are female with an average household size of 4.4 people. The capital city is populated by different ethnic groups including the Gogo, Rangi, and Sandawe with small Indian minorities (CCD, 2020). Topographically, the city extends from elevation ranging between 900 to 1000 m above the mean sea level. The climatic condition is semi-arid characterized by a notable seasonal rainfall with a long dry and short wet season of an average annual rainfall of about 300 – 800 mm per year, with annual potential evapotranspiration of 2000 mm (CCD, 2020; Massawe et al., 2017). Economically, about 25% of the population within the city is engaged in petty business, small and medium scale industries, consultancy activities, construction works, transportation, social and administrative services (CCD, 2020).

Materials and methods

The current study is mainly focused on selecting potential landfill sites using GIS-based MCDA for appropriate solid waste management practices in Dodoma capital city. Influencing criteria from various disciplines were identified, analysed, and standardized in ArcGIS 10.6 environments. AHP and WLC methods were employed in ArcGIS pro software to simplify the decision, where landfills sites were determined and ranked. Finally, candidate landfills' sites were identified and verified in the field.

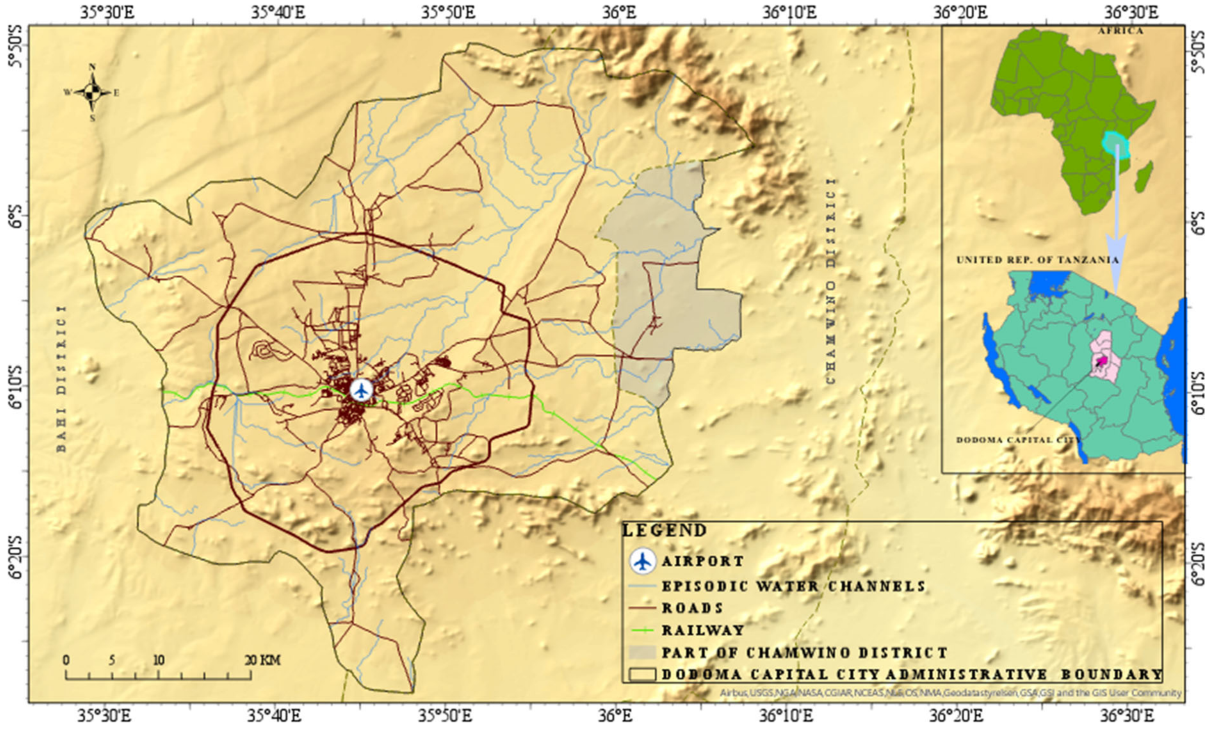


Fig. 1 Location of the study area and the administrative boundary of Dodoma capital city

Geospatial data acquisition and preparation

The current study employed technical, logical, qualitative, and quantitative methodologies. Technically, landfill sites selection criteria were determined from various kinds of literature where fifteen influencing criteria were selected including proximity from built-up, surface water, episodic water channels, boreholes, sensitive sites, protected areas, major faults, LULC, lithology/geology, soil type, elevation, slopes, proximity from airport, roads, railway and earthquake epicentres where both primary and secondary data sources were used (Fig. 2a–c). This was accomplished by various software such as ArcGIS 10.6, ArcGIS Pro, and ERDAS imagine 2015. Landsat 8 OLI satellite imageries obtained from (https://earthexplorer.usgs.gov) with a spatial resolution of 30 m were used to prepare LULC thematic maps with the help of field investigation. Shuttle Radar Topographic Mission (SRTM) Digital Elevation Model (DEM) dataset of 30 m spatial resolution also obtained from (https://earthexplorer.usgs.gov) was used in the preparation of primary thematic datasets including slopes, elevations, streams, and drainage density. In the study area, open dumpsites, existing landfills, waste collection points, boreholes, sensitive sites, protected areas, and airport datasets were collected with the help of a handheld global positioning system (GPS). Also, earthquake epicentres, soil maps, transport networks (roads and railway lines), and geology datasets were used in this study. All criteria were then geo-referenced to UTM Projection system zone 36 s. Vector datasets were rasterized and resampled into 30 m spatial resolution and finally, all inputs datasets were reclassified, ranked, and then standardized into; unsuitable, less suitable, moderately, suitable and highly suitable zones with their assigned respective weights ranging from 1–5, using spatial analyst tool in ArcGIS Pro software. All thematic datasets were assigned weights by the AHP technique, where the consistency ratio was evaluated. These datasets were then integrated by the WLC technique and solid waste landfills sites suitability map was produced. Finally, highly suitable sites in the study area were determined based on proximity distance from residential areas and their sizes, in which the three best landfill sites were determined and ranked. The methodological framework employed in the current study is shown in Fig. 3 below.

Ranking criterion weights

Fifteen influencing criteria were involved for the site selection process where the AHP technique was employed for weighting criteria relating to landfills location. The following steps were employed:

Pairwise comparison of matrix analysis

All reclassified influencing criteria involved in this study were analyzed to obtain highly suitable sites where a pairwise comparison of the matrix (Aw) was built to determine the importance of each factor relative to the other based on Saaty's scale (Table 1). AHP has been a powerful tool in weighting criteria and can determine inconsistency in the datasets by computing consistency ratios (Sisay et al., 2020).

Each factor was weighted with respect to its suitability in landfills site selection, where a set of criteria summing to 1 in the diagonal cells was developed (Table 2). The higher the influencing weight of a factor the important it is; derived by (Eq. 1)

$$Aw = \left(a_{ij}\right)_{n*n} = \begin{bmatrix} a_{11} & a_{12} & \ldots a_{1n} \\ a_{21} & a_{22} & \ldots a_{2n} \\ a_{n1} & a_{n2} & \ldots a_{nn} \end{bmatrix} X \begin{bmatrix} w1 \\ w2 \\ wj \end{bmatrix}, a_{ii} = 1, a_{ij} = \frac{1}{a_{ji}}, a_{ij} \neq 0 \tag{1}$$

In this study, $\lambda_{max} = 15.91$, CI = 0.065, $RI_{15-} = 1.59$ and CR = 0.041 $\leq$ 0.1 accepted (Saaty, 1980).

Eigenvector (λ_{max}) weight calculation

Eigenvectors of each factor were calculated, where the values were normalized and each cell divided by the column sum and rows. Finally, summed and divided for the several criteria (Table 3); Computed by (Eq. 2).

$$\lambda \max = \frac{1}{n} \sum_{wi}^{n} \frac{(AW)i}{wi} \tag{2}$$

whereas, W is the corresponding principal eigenvector, W_i is the value of the corresponding weight of criteria, and i = 1, 2... n is the number of criteria involved.

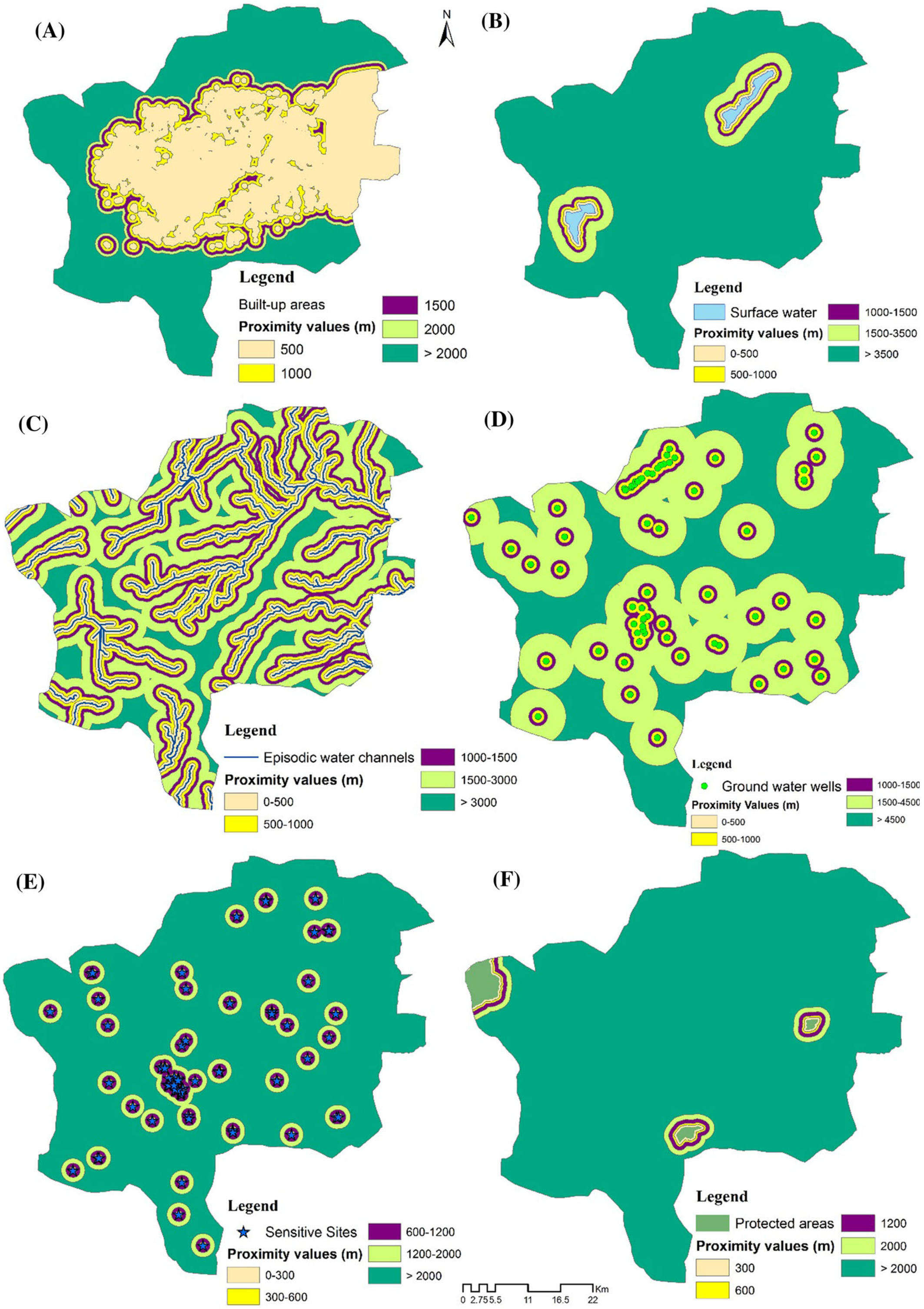


Fig. 2 **a** Criteria: **a** built-up areas, **b** surface water, **c** episodic water channels, **d** boreholes, **e** sensitive sites, **f** protected areas. **b** Criteria: **g** major faults, **h** LULC, **i** geology/lithology, **j** soil types, **k** elevation, **l** slopes. **c** Criteria: **m** airports, **n** roads and railway, **o** earthquake epicentres

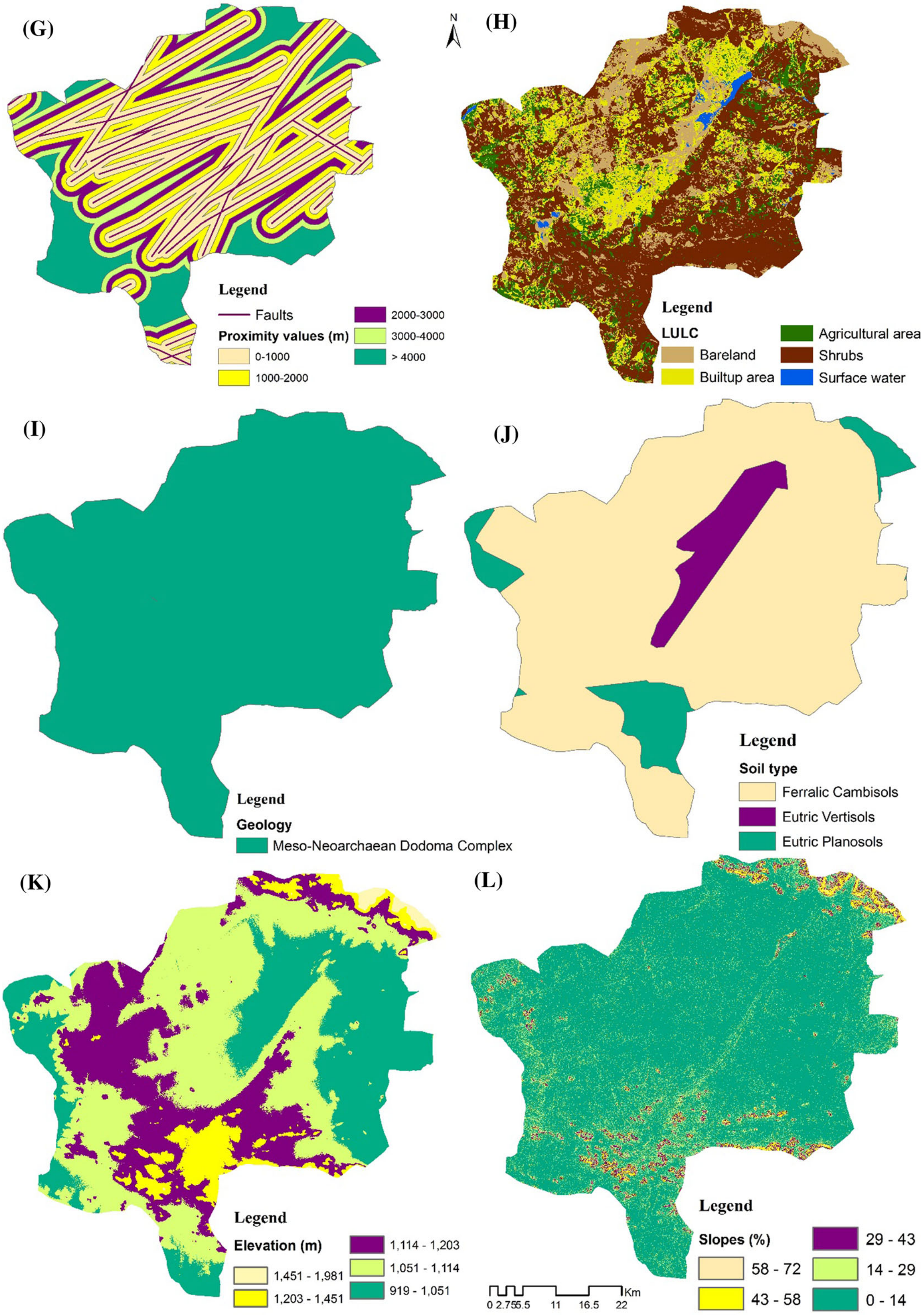


Fig. 2 continued

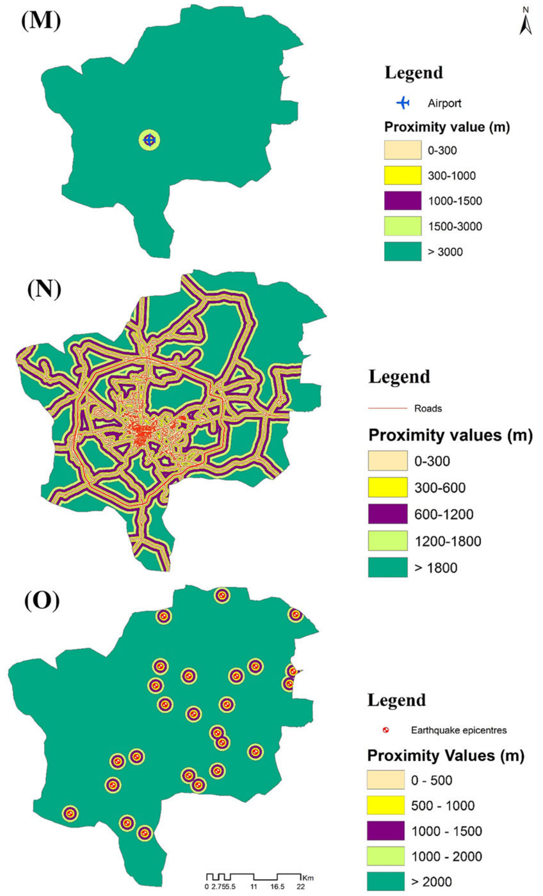


Fig. 2 continued

Calculation of consistency ratio (CR)

CR of a matrix in AHP is computed to access the consistency of the employed judgment during weighting of the criteria (Saaty, 1980) and is evaluated by computation of the consistency index (CI) given by (Eq. 3). In the current study, CR was computed by (Eq. 4).

$$CI = \frac{\lambda \max - n}{n - 1} \tag{3}$$

$$CI = \frac{(15.91 - 15)}{(15 - 1)} = 0.065$$

CR is given by;

Table 1 Fundamental 1 to 9 Saaty's scale of relative importance (Saaty, 1980)

Degree of importance	Definition
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2, 4, 6, 8	Intermediate values

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

$$CR = \frac{0.065}{RI = 1.59} = 0.041$$

whereas, *RI* signifies the random index. The *RI* values are employed to compute the CR and it depends on the number of criteria involved (Table 4). In this study, the *RI* value is 1.59.

Weighted Linear Combination (WLC) analysis

All contributing criteria were integrated based on their weights $(\boldsymbol{r_i})$ (Table 5) and solid waste landfill suitability classes (SWLSC) map was calculated based on the WLC method in ArcGIS Pro environment.

WLC method is defined by the following expression (Eq. 5):

$$SWLSC = \sum_{i=1}^{n} (w_i \times r_i) \tag{5}$$

whereas; w_i is the weight value of each contributing criteria, r_i (1 = 1, 2……n) signifies the normalized ranking of criteria and n signifies the number of contributing criteria.

Results and Discussion

Influencing criteria suitability analysis

Built-up suitability

Landfills should be placed away from residential areas to avoid smell and pollutions produced from wastes.

These proximity distances were determined based on other studies elsewhere (Balew et al., 2020; Jerie & Zulu, 2017; Nas et al., 2010; Sisay et al., 2020). In this study, the minimum safest proximity distance from the residential area was determined by considering the city growth rate. A distance of less than 500 m was considered as unsuitable, (500–1000 m) less suitable, (1000–1500 m) moderately suitable, (2000–2500 m) suitable, and finally greater than 2500 m as highly suitable for landfills placement (Fig. 4a). Built-up suitability shows that 40.2%, 7.2%, and 3.9% of the study area is unsuitable, less suitable, and moderately suitable zones while 3% and 45.7% of the area is suitable, and highly suitable respectively (Table 5).

Proximity from surface water suitability

To determine the proximity distance from surface water to landfills' areas of placement, various works of literature were considered (Balew et al., 2020; Lentswe & Molwalefhe, 2020; Sisay et al., 2020). Areas far from surface water bodies were considered suitable for landfill sites. A proximity distance less than 500 m was determined as unsuitable, (500–1000 m) as less suitable, (1000–1500 m) moderately suitable, (1500–3500 m) suitable, and greater than 3500 m as highly suitable (Fig. 4a). The results show that 89.2% of the study is highly suitable, 6.1% suitable, 1.3% moderately suitable while 1.2% and

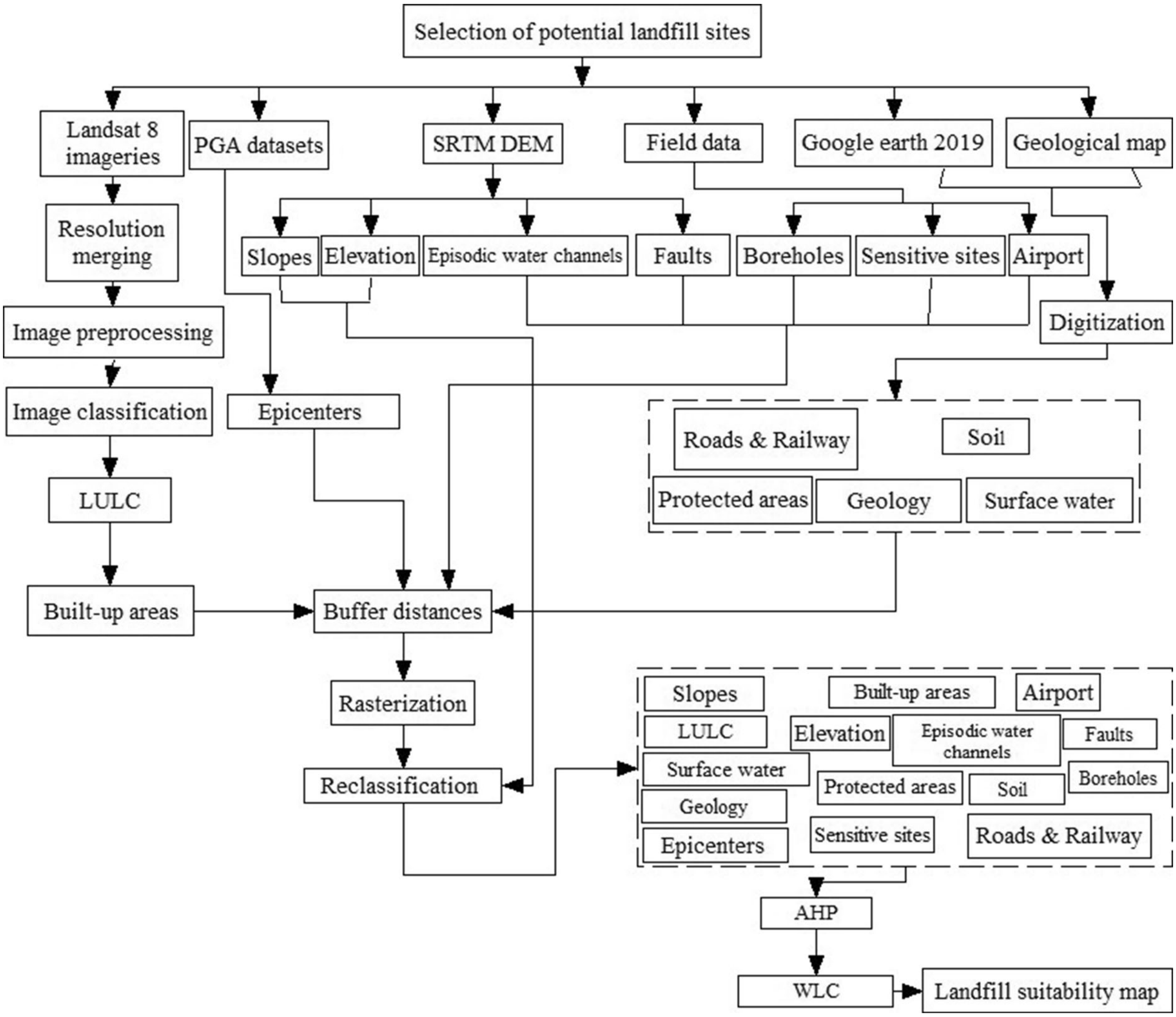


Fig. 3 Methodological framework employed in this study

Table 2 Pairwise comparison matrix of the influencing criteria

Criteria	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
A	1.00	2.00	2.00	3.00	2.00	3.00	4.00	5.00	6.00	4.00	7.00	5.00	7.00	9.00	8.00
B	0.50	1.00	2.00	2.00	2.00	2.00	3.00	4.00	6.00	7.00	6.00	7.00	9.00	8.00	9.00
C	0.50	0.50	1.00	2.00	2.00	2.00	3.00	2.00	4.00	6.00	5.00	6.00	7.00	5.00	9.00
D	0.33	0.50	0.50	1.00	2.00	2.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	8.00
E	0.50	0.50	0.50	0.50	1.00	2.00	2.00	3.00	4.00	5.00	6.00	7.00	6.00	8.00	7.00
F	0.33	0.50	0.50	0.50	0.50	1.00	2.00	2.00	3.00	2.00	3.00	4.00	5.00	9.00	8.00
G	0.25	0.33	0.33	0.50	0.50	0.50	1.00	2.00	2.00	2.00	3.00	3.00	4.00	6.00	9.00
H	0.20	0.25	0.50	0.33	0.33	0.50	0.50	1.00	2.00	2.00	3.00	4.00	5.00	6.00	9.00
I	0.17	0.17	0.25	0.25	0.25	0.33	0.50	0.50	1.00	2.00	2.00	3.00	4.00	3.00	6.00
J	0.25	0.14	0.17	0.20	0.20	0.50	0.50	0.50	0.50	1.00	2.00	2.00	3.00	4.00	5.00
K	0.14	0.17	0.20	0.17	0.17	0.33	0.33	0.33	0.50	0.50	1.00	2.00	2.00	2.00	3.00
L	0.20	0.14	0.17	0.14	0.14	0.25	0.33	0.25	0.33	0.50	0.50	1.00	2.00	3.00	4.00
M	0.14	0.11	0.14	0.13	0.17	0.20	0.25	0.20	0.25	0.33	0.50	0.50	1.00	2.00	3.00
N	0.11	0.13	0.20	0.11	0.13	0.11	0.17	0.17	0.33	0.25	0.50	0.33	0.50	1.00	2.00
O	0.13	0.11	0.11	0.13	0.14	0.13	0.11	0.11	0.17	0.20	0.33	0.25	0.33	0.50	1.00
SUM	4.76	6.55	8.57	10.95	11.53	14.85	19.69	24.06	34.08	37.78	45.83	52.08	63.83	75.50	91.00

Whereas, A; built-up areas; B, surface waters; C, episodic water channels; D, boreholes; E, sensitive sites; F, protected areas; G, major faults; H, LULC; I, geology; J, soil type; K, elevation; L, slopes; M, airport; N, roads and railway; O, earthquake epicentres

2.3% were under less suitable, and unsuitable zones respectively (Table 5).

Proximity from episodic channels suitability

These are water channels formed from surface run-off only occurring during heavy rain season and usually form permanent paths (Boulton & Lake, 1988). They are dominant in arid and semi-arid regions only containing water on unpredictable basis (Arthington et al., 2014). Areas far from these channels were considered suitable for landfill sites (Balew et al., 2020; Lentswe & Molwalefhe, 2020; Sisay et al., 2020) to avoid groundwater contamination through leachate (Rikta et al., 2018). A proximity distance less than 500 m was determined as unsuitable, (500–1000 m) as less suitable, (1000–1500 m) moderately suitable, (1500–3000 m) suitable, and greater than 3000 m as highly suitable (Fig. 4a). Episodic channel suitability shows that 12.1% of the area was highly suitable, 33.5% suitable, 15.8% moderately suitable, 17.8% less suitable, and 20.8% unsuitable respectively for landfills site location (Table 5).

Proximity from boreholes suitability

Landfill sites should not be positioned within a proximity distance of 500 m from any deep or shallow boreholes (Mussa & Suryabhagavan, 2019; Ngumom & Terseer, 2015). In the current study, based on different pieces of literature elsewhere (Gizachew, 2011; Singh et al., 2017), a proximity distance of less than 500 m was considered unsuitable, (500–1000 m) less suitable, (1000–1500 m) moderately suitable, (1500–4500 m) suitable and above 4500 m as highly suitable (Fig. 4a). From the analysis, 41.6%, 47.4%, and 5.5% of the total study area are highly suitable, suitable, and moderately suitable respectively while 3.9% and 1.6% are less suitable and unsuitable respectively (Table 5).

Table 3 Normalized matrix of the influencing criteria

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	λ_{max}	Weights (%)
A	0.210	0.305	0.233	0.274	0.173	0.202	0.203	0.208	0.176	0.106	0.153	0.096	0.110	0.119	0.088	0.177	17.71
B	0.105	0.153	0.233	0.183	0.173	0.135	0.152	0.166	0.176	0.185	0.131	0.134	0.141	0.106	0.099	0.152	15.15
C	0.105	0.076	0.117	0.183	0.173	0.135	0.152	0.083	0.117	0.159	0.109	0.115	0.110	0.066	0.099	0.120	12.00
D	0.070	0.076	0.058	0.091	0.173	0.135	0.102	0.125	0.117	0.132	0.131	0.134	0.125	0.119	0.088	0.112	11.19
E	0.105	0.076	0.058	0.046	0.087	0.135	0.102	0.125	0.117	0.132	0.131	0.134	0.094	0.106	0.077	0.102	10.17
F	0.070	0.076	0.058	0.046	0.043	0.067	0.102	0.083	0.088	0.053	0.065	0.077	0.078	0.119	0.088	0.074	7.43
G	0.053	0.051	0.039	0.046	0.043	0.034	0.051	0.083	0.059	0.053	0.065	0.058	0.063	0.079	0.099	0.058	5.83
H	0.042	0.038	0.058	0.030	0.029	0.034	0.025	0.042	0.059	0.053	0.065	0.077	0.078	0.079	0.099	0.054	5.39
I	0.035	0.025	0.029	0.023	0.022	0.022	0.025	0.021	0.029	0.053	0.044	0.058	0.063	0.040	0.066	0.037	3.70
J	0.053	0.022	0.019	0.018	0.017	0.034	0.025	0.021	0.015	0.026	0.044	0.038	0.047	0.053	0.055	0.032	3.25
K	0.030	0.025	0.023	0.015	0.014	0.022	0.017	0.014	0.015	0.013	0.022	0.038	0.031	0.026	0.033	0.023	2.27
L	0.042	0.022	0.019	0.013	0.012	0.017	0.017	0.010	0.010	0.013	0.011	0.019	0.031	0.040	0.044	0.021	2.14
M	0.030	0.017	0.017	0.011	0.014	0.013	0.013	0.008	0.007	0.009	0.011	0.010	0.016	0.026	0.033	0.016	1.57
N	0.023	0.019	0.023	0.010	0.011	0.007	0.008	0.007	0.010	0.007	0.011	0.006	0.008	0.013	0.022	0.012	1.24
O	0.026	0.017	0.013	0.011	0.012	0.008	0.006	0.005	0.005	0.005	0.007	0.005	0.005	0.007	0.011	0.01	0.96
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	100.00

Sensitive sites suitability

The proximity distance of less than 300 m was determined as unsuitable for placement of landfill, (300–600 m) less suitable, (600–1200 m) moderately suitable, (1200–2000 m) as suitable and greater than 2000 m determined as highly suitable (Alavi et al., 2013) (Fig. 4a). Sensitive site suitability analysis shows that 83.3%, 10.1%, and 4.7% of the study area were determined as highly suitable, suitable, and moderately suitable respectively while 1.4% and 0.6% were less suitable and unsuitable zones respectively (Table 5).

Proximity from protected areas suitability

Basing on various studies, ranges of proximity distance from protected areas were determined (Alavi et al., 2013; Sisay et al., 2020). Proximity distance of less than 300 m was considered unsuitable, (300–600 m) less suitable, (600–1200 m) moderately suitable, (1200–2000 m) suitable, and more than 2000 m as highly suitable (Fig. 4a). The analysis revealed that highly suitable zones, suitable, moderately suitable, less suitable, and unsuitable areas were 95.6%, 1.5%, 0.9%, 0.4%, and 1.6% of the study area respectively (Table 5).

Proximity from faults suitability

Basing on other studies (Balew et al., 2020; Mussa & Suryabhagavan, 2019), proximity range of (0–1000 m), (1000–2000 m), (2000–3000 m), (3000–4000 m), and greater than 4000 m was determined as unsuitable, less suitable, moderately suitable, suitable and highly suitable for analysis respectively (Fig. 4a). This is because areas near the faults result in a high rate of permeability and leachate which may lead to contamination of groundwater (Rikta et al., 2018). The area is mainly characterized by faults pointing northeast to southwest of the study area. From faults suitability analysis, 16.6%, 9.5%, and 14.1% of the study area were determined as highly suitable, suitable, and moderately suitable respectively while 22.4% and 37.4% of the area were found to be less suitable and unsuitable zones respectively (Table 5).

LULC suitability

LULC map of the study area was reclassified into: (i) built-up areas; (ii) water bodies; (iii) agricultural land (iv) bare land and (vi) shrubs (Fig. 4a). Landfill should not be placed near human settlement to avoid human and environmental effects and for future developments (Sisay et al., 2020), however open fields and bare land are highly suitable for landfills placement (Balew et al., 2020) followed by low economic value lands like shrub lands (Yeshodha & Karthihenyah, 2016). LULC suitability analysis shows that highly suitability areas are covered by bare lands (51.1%) followed by shrubs (15.4%) as suitable and agricultural areas (10.7%) as moderately suitable whereas built-up areas (21.7%), and water bodies (1.0%) falls under less suitable and unsuitable zones respectively (Table 5).

Geological suitability

Lithological suitability was determined based on various kinds of literature. The area is characterized by Meso-neoarchaean Dodoma complex main lithological unit (Fig. 4a) which is highly suitable for landfill placement within the study area. Lithology with higher permeability rates accelerates the infiltration process thus unsuitable for locating landfills (Bonacci et al., 2006; Msabi & Makonyo, 2020).

Soil suitability

Soil suitability was determined based on their permeability and coarseness. Soil with high unconsolidated materials is considered highly suitable for analysis

Table 4 Random consistency index (Saaty, 1980)

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

When the *CR* value is < 0.10 calculation is acceptable otherwise it should be recalculated (Saaty, 1980)

Table 5 Criteria for landfill sites selection, suitability, and their rank

Criteria	Parameters (m)	Suitability class	Rank	Areas (ha)	Area (%)	Weight (ri) %
Built-up areas	0–500	Unsuitable	1	114,507.5	40.2	17.71
	500–1000	Less suitable	2	20,581.4	7.2	
	1000–1500	Moderately suitable	3	11,078.4	3.9	
	2000–2500	Suitable	4	8565.4	3.0	
	> 2500	Highly suitable	5	130,211.7	45.7	
Surface water	0–500	Unsuitable	1	74.7	2.3	15.15
	500–1000	Less suitable	2	38.2	1.2	
	1000–1500	Moderately suitable	3	41.4	1.3	
	1500–3500	Suitable	4	196.2	6.1	
	> 3500	Highly suitable	5	2885.2	89.2	
Episodic water channels	0–500	Unsuitable	1	673.9	20.8	12.00
	500–1000	Less suitable	2	576.5	17.8	
	1000–1500	Moderately suitable	3	510.4	15.8	
	1500–3000	Suitable	4	1084.1	33.5	
	> 3000	Highly suitable	5	390.8	12.1	
Boreholes	0–500	Unsuitable	1	4593.0	1.6	11.19
	500–1000	Less suitable	2	11,057.8	3.9	
	1000–1500	Moderately suitable	3	15,676.9	5.5	
	1500–4500	Suitable	4	134,995.1	47.4	
	> 4500	Highly suitable	5	118,621.6	41.6	
Sensitive sites	0–300	Unsuitable	1	17.9	0.6	10.17
	300–600	Less suitable	2	43.8	1.4	
	600–1200	Moderately suitable	3	151.3	4.7	
	1200–2000	Suitable	4	326.7	10.1	
	> 2000	Highly suitable	5	2695.9	83.3	
Protected areas	0–300	Unsuitable	1	52.9	1.6	7.43
	300–600	Less suitable	2	12.3	0.4	
	600–1200	Moderately suitable	3	28.1	0.9	
	1200–2000	Suitable	4	47.6	1.5	
	> 2000	Highly suitable	5	3094.7	95.6	
Faults	0–1000	Unsuitable	1	106,691.5	37.4	5.83
	1000–2000	Less suitable	2	63,760.1	22.4	
	2000–3000	Moderately suitable	3	40,139.5	14.1	
	3000–4000	Suitable	4	27,134.1	9.5	
	> 4000	Highly suitable	5	47,219.2	16.6	
LULC	Water bodies	Unsuitable	1	2978.8	1.0	5.39
	Built-up areas	Less suitable	2	61,856.0	21.7	
	Agricultural area	Moderately suitable	3	30,413.2	10.7	
	Shrubs	Suitable	4	43,963.3	15.4	
	Bare land	Highly suitable	5	145,733.0	51.1	
Geology	Meso-Neoarchaean Dodoma complex	Highly suitable	5	284,944.4	100.0	3.70
Soil type	Ferralic cambisols	Unsuitable	1	204.7	6.3	3.25
	Eutric vertisols	Moderately suitable	3	259.9	8.0	
	Eutric planosols	Highly suitable	5	2771.1	85.6	

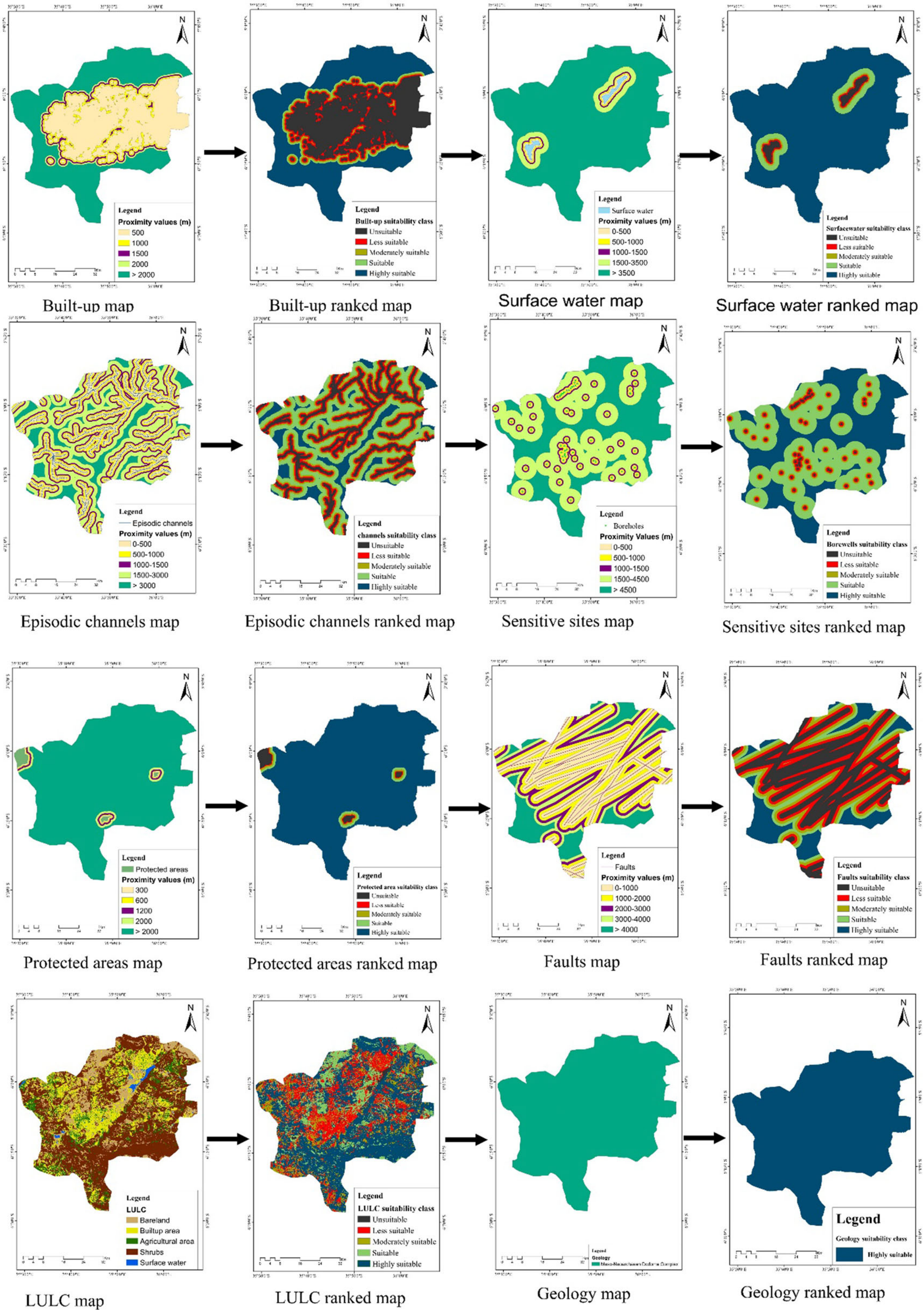
Table 5 continued

Criteria	Parameters (m)	Suitability class	Rank	Areas (ha)	Area (%)	Weight (ri) %
Elevation	> 1451	Unsuitable	1	368.1	0.1	2.27
	1203–1451	Less suitable	2	1285.2	0.5	
	1114–1203	Moderately suitable	3	2307.8	0.9	
	1051–1114	Suitable	4	58,601.3	21.9	
	919–1051	Highly suitable	5	204,840.4	76.6	
Slopes	> 58%	Unsuitable	1	489.6	0.2	2.14
	43%—58%	Less suitable	2	4535.4	1.7	
	29%—43%	Moderately suitable	3	6944.3	2.6	
	14%—29%	Suitable	4	34,399.7	12.8	
	0%—14%	Highly suitable	5	221,367.9	82.7	
Airport	0–300	Unsuitable	1	0.4	0.0	1.57
	300–1000	Less suitable	2	3.3	0.1	
	1000–1500	Moderately suitable	3	4.6	0.1	
	1500–3000	Suitable	4	23.9	0.7	
	> 3000	Highly suitable	5	3,203.6	99.0	
Roads &Railway	0–300	Unsuitable	1	613.5	19.0	1.24
	300–600	Less suitable	2	410.8	12.7	
	600–900	Moderately suitable	3	609.0	18.8	
	900–1200	Suitable	4	442.5	13.7	
	> 1200	Highly suitable	5	1159.8	35.8	
Earthquake epicentres	0–500	Unsuitable	1	21.8	0.7	0.96
	500–1000	Less suitable	2	67.2	2.1	
	1000–1500	Moderately suitable	3	107.1	3.3	
	1500–2000	Suitable	4	141.3	4.4	
	> 2000	Highly suitable	5	2898.3	89.6	

(Gizachew, 2011). The area consists of three major types of soil Eutric planosols which contain small particles hence low transmissions and permeability rate; considered as the most suitable. Eutric vertisols and Ferralic cambisols have weak and fine-textured materials that were reclassified and ranked as moderately suitable and unsuitable respectively (Fig. 4b). The results from the analysis revealed that about 85.7% of the soil within the study area is suitable, 8% moderately suitable, and 6.3% is unsuitable for analysis (Table 5).

Elevation suitability

Higher elevated areas are unsuitable for locating landfills, this is to avoid construction expenses. This criterion is widely used in various studies worldwide (Kazuva et al., 2020; Torabi-Kaveh et al., 2016; Wang et al., 2009). In this study elevation ranging from (919 –1051 m), (1051–1114 m), (1114–1203 m), (1203–1451 m), and greater than 1451 m were determined and ranked as highly suitable, suitable, moderately suitable, less suitable and unsuitable respectively (Fig. 4b). The results show that 76.6%, 21.9%, and 0.9% of the study area are highly suitable, suitable, and moderately



Built-up map

Built-up ranked map

Surface water map

Surface water ranked map

Episodic channels map

Episodic channels ranked map

Sensitive sites map

Sensitive sites ranked map

Protected areas map

Protected areas ranked map

Faults map

Faults ranked map

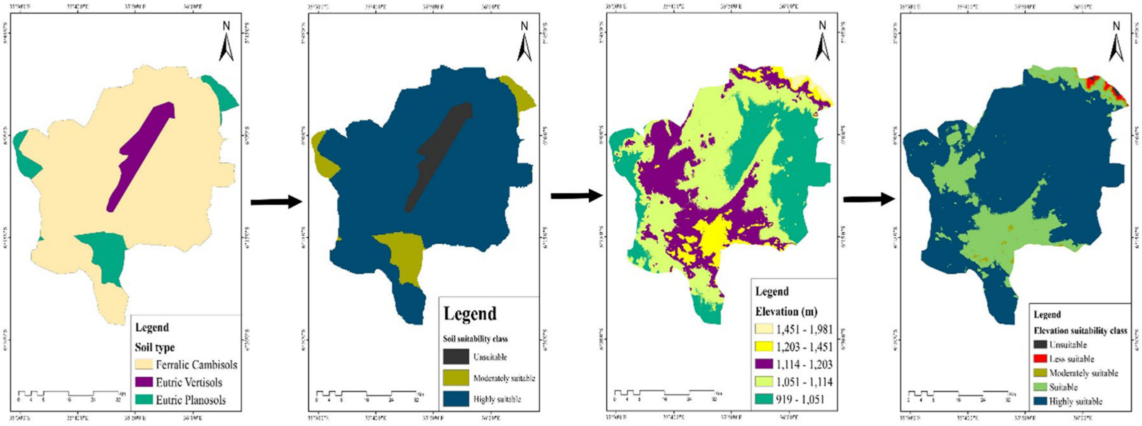
LULC map

LULC ranked map

Geology map

Geology ranked map

Fig. 4 **a** Original and reclassified thematic maps. **b** Original and reclassified thematic maps

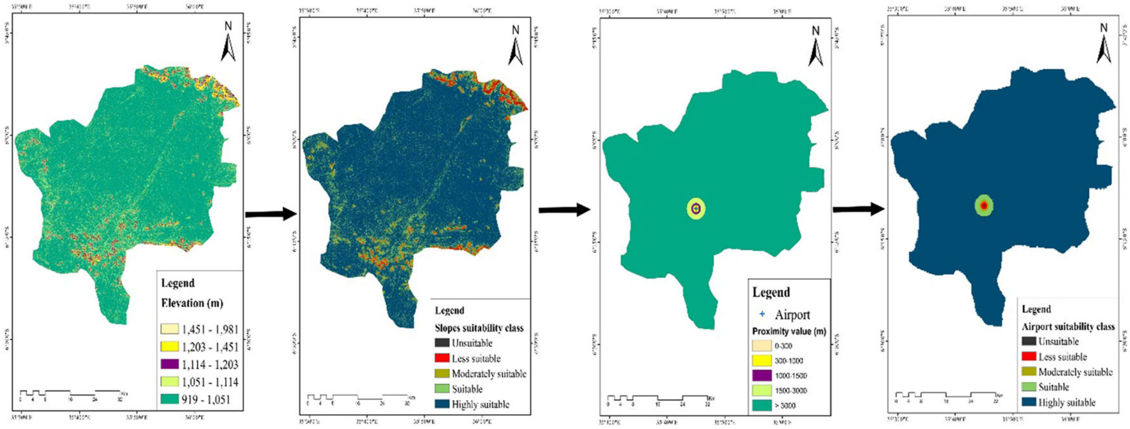


Soil type map

Soil type ranked map

Elevation map

Elevation ranked map

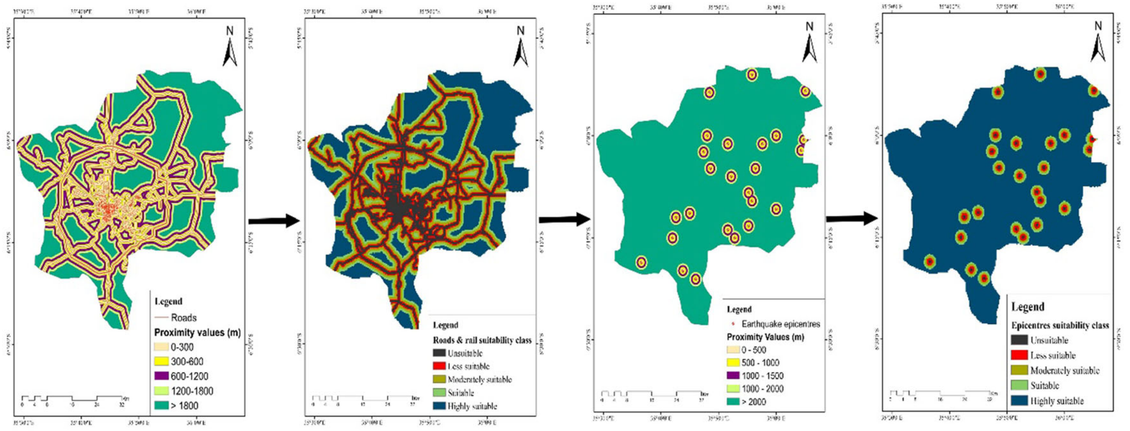


Slopes map

Slopes ranked map

Airport map

Airport ranked map



Roads & Railway map

Roads & Railway ranked map

Epicentres map

Epicentres ranked map

Fig. 4 continued

suitable respectively while 0.5%, and 0.1 area less suitable and unsuitable for analysis respectively (Table 5).

Slopes suitability

Various ranges of slopes affect the landfill siting process (Assay, 2020), steep sloping areas may result in erosion and high construction costs. Slopes suitability is determined based on other studies (Ebistu & Minale, 2013; Mussa & Suryabhagavan, 2019; Sisay et al., 2020). Slopes were reclassified into: (0–14%) as highly suitable, (14–29%) suitable, (29–43%) moderately suitable, (43–58%) less suitable and greater than 58% as unsuitable (Fig. 4b). However, a slope less than 20% is highly preferred for landfill placement (Hasan et al., 2009; Safavian et al., 2015). From the analysis, 82.7%, 12.8%, and 2.6% of the total study area are highly suitable, suitable, and moderately suitable respectively while 1.7% and 0.2% of the area are less suitable and unsuitable respectively (Table 5).

Proximity from airport suitability

Different researchers have assigned different ranges of proximity distance to be maintained from airports to areas of landfills. This is to prevent the attraction of birds to landfills which may cause danger to flying aircraft (Sisay et al., 2020). Thus, a proximity buffer zone of less than 300 m was considered unsuitable, (300–1000 m), (1000–1500 m), (1500–3000 m), and greater than 3000 m as less suitable, moderately suitable, suitable, and highly suitable for landfill site selection respectively (Fig. 4b). The results indicate that about 99% of the total area is highly suitable for the analysis (Table 5).

Proximity from roads and railway suitability

Landfill should not be too close to roads and railway lines to avoid the congestion of trucks to and from landfills (Balew et al., 2020; Yesilnacar et al., 2012). Also, areas too far from roads are not recommended to avoid the expenses of constructing new minor roads to landfills (Balew et al., 2020; Sisay et al., 2020). Basing on other studies a proximity distance of at least 100 to 300 m should be maintained on primary class roads (Cantwell, 1999; Leao et al., 2004). A distance of less than 300 m (19%) was considered as unsuitable, (300—600 m) less suitable, (600—900 m) moderately suitable, and (900—1200 m) away from major roads as highly suitable (Fig. 4b). The suitability analysis shows 12.7%, 18.8%, and 13.7% are less suitable, moderately suitable, and suitable respectively while 35.8% of the area is highly suitable (Table 5).

Proximity from earthquake epicentres suitability

Earthquake-prone areas were identified in the study area. A proximity distance less than 500 m was determined as unsuitable, (500–1000 m) less suitable, (1000–1500 m) moderately suitable, (1500–2000 m) suitable, and greater than 2000 m determined as highly suitable basing on various works of literature (Bagchi, 2004; Yesilnacar et al., 2012) (Fig. 4b). In the current study, 89.6%, 4.4%, and 3.3% are highly suitable, suitable and moderately suitable areas respectively while 2.1% and 0.7% are under less suitable and unsuitable zone respectively (Table 5).

Suitability model

All reclassified thematic datasets were integrated by WLC (Fig. 5) using (Eq. 5) and finally, a solid waste landfill suitability classes (SWLSC) map of Dodoma capital city was produced.

$$\text{SWLSC} = ((\text{built up area} \times 0.177) + (\text{surface water} \times 0.152) + (\text{episodic water channels} \times 0.120) + (\text{boreholes} \times 0.112) + (\text{sensitive sites} \times 0.102) + (\text{protected areas} \times 0.074) + (\text{major faults} \times 0.058) + (\text{LULC} \times 0.054) + (\text{lithology/geology} \times 0.037) + (\text{soil type} \times 0.032) + (\text{elevation} \times 0.023) + (\text{slopes} \times 0.021) + (\text{airport} \times 0.016) + (\text{roads \& railway line} \times 0.012) + (\text{earthquake epicentres} \times 0.0096)) = \text{WLC (Fig. 5)}.$$

Solid waste landfill suitability sites map

In the current study, the results reveal that 41,177 ha (14.7%) of the study area is found to be highly suitable as it satisfies both environmental, social, economic, and technical criteria for landfills placement. Conversely, 83,930 ha (30%), 84,305 ha (30.2%), and 53,508 ha (19.1%) of the area are suitable, moderately suitable, and less suitable respectively while 16,683 ha (6%) is under unsuitable zone (Fig. 6). The analysis shows that south-western,

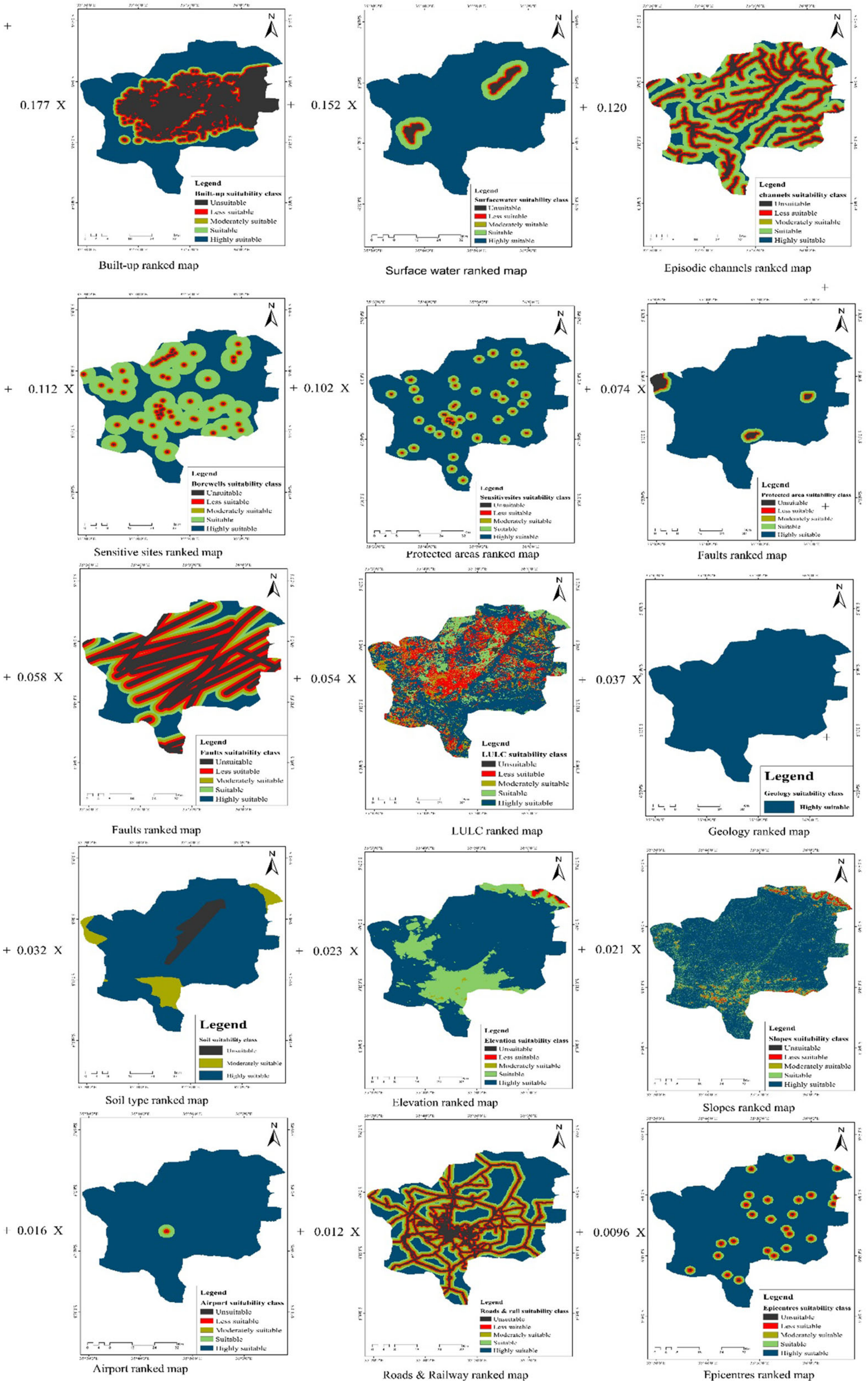


Fig. 5 Integrated reclassified suitability thematic maps

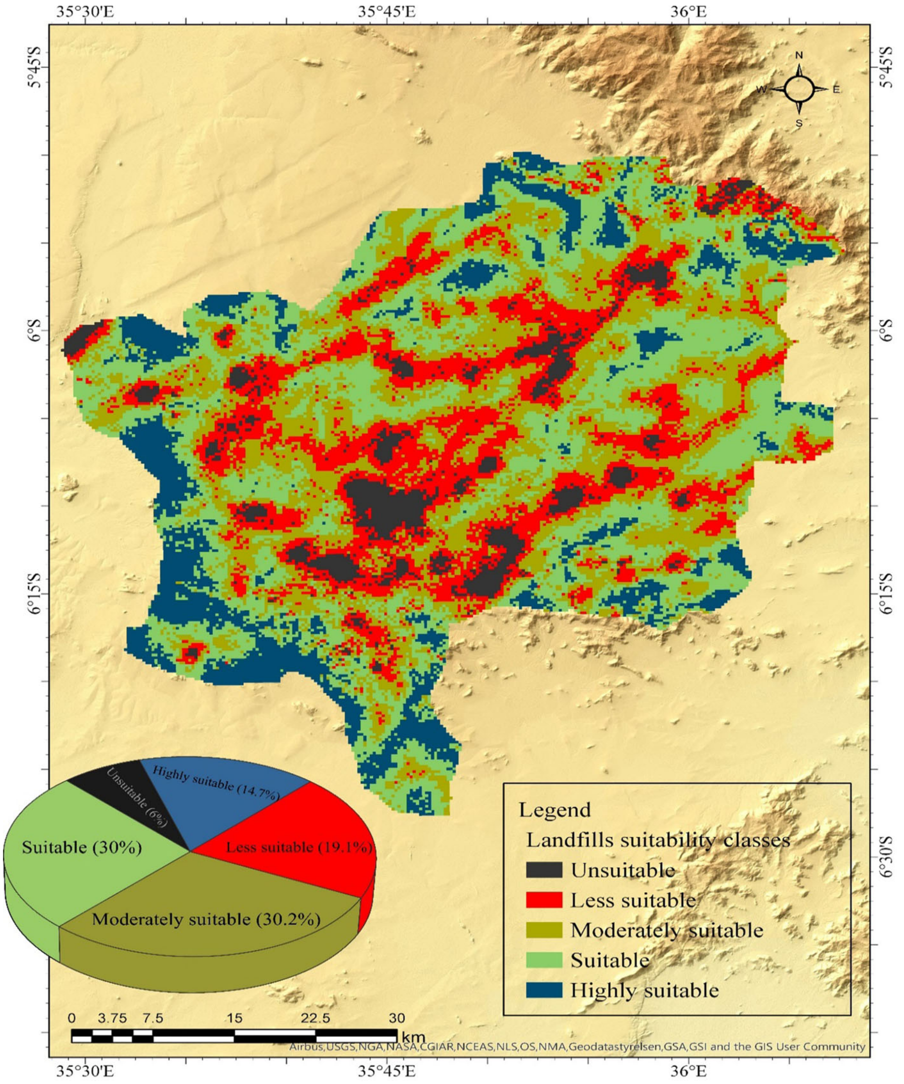


Fig. 6 Solid waste landfill sites suitability map of the study area

northern, and most parts of the south-eastern within the study area are highly suitable sites for landfills. Therefore, the remaining parts did not satisfy both environmental, social, economic, and technical criteria hence excluded for further analysis.

Highly suitable landfill sites map

A thematic map was generated from the solid waste landfill suitability map (Fig. 6) showing only highly suitable landfill sites within the area (Fig. 7). The results indicate that highly suitable sites are mostly concentrated in the south-western and north-eastern parts of the study area.

Prioritizing highly suitable candidate landfill sites

Highly suitable landfill site prioritization was evaluated basing on various parameters including distance from the residential areas and their sizes. Large landfill sites may be highly suitable basing on the size but unfitting on proximity from residential areas perspective. Discontinuous and very small-sized identified suitability sites are excluded for analysis to avoid

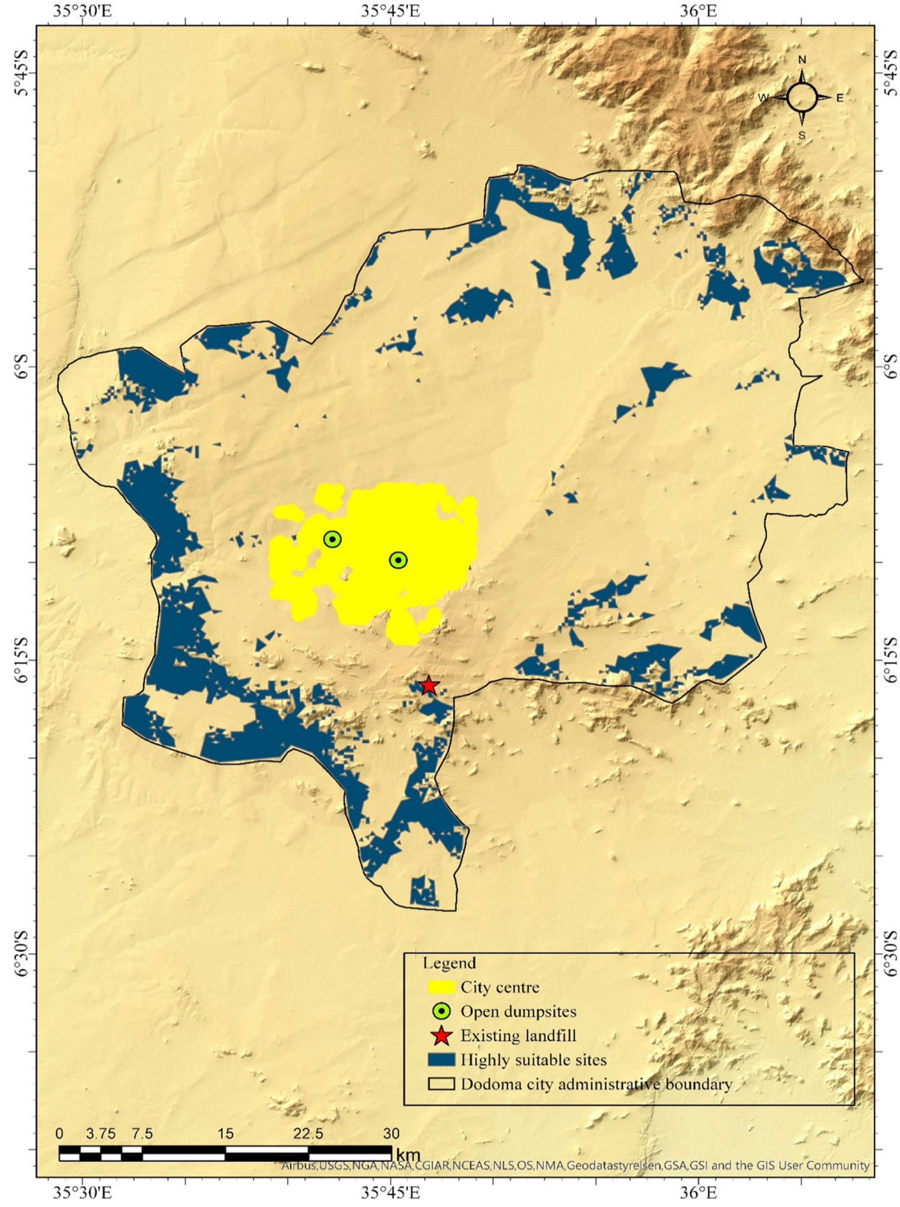


Fig. 7 Highly suitable landfill sites

reconstruction costs as they can be filled out in a few years of use (Sisay et al., 2020). Hence, eleven candidate landfill sites were identified in this study for further analysis (Fig. 8).

The size of the landfill sites and the proximity distance from residential areas criteria were evaluated against each other to help rank identified sites (Table 6).

Therefore, the area was computed for each identified site, whereby larger landfill sites are mostly preferred as compared to small ones as they can be used for a long time without reconstruction (Gizachew, 2011; Sisay et al., 2020). Consequently, each landfill size was evaluated against each other and the results expose that landfill sites 3, 2, and 5 are highly suitable with eigenvectors 0.185, 0.147, and 0.110 respectively, (Table 7).

Likewise, landfills should be located at a convenient distance from residential areas and the city centre to avoid high transportation costs (Sisay et al.,

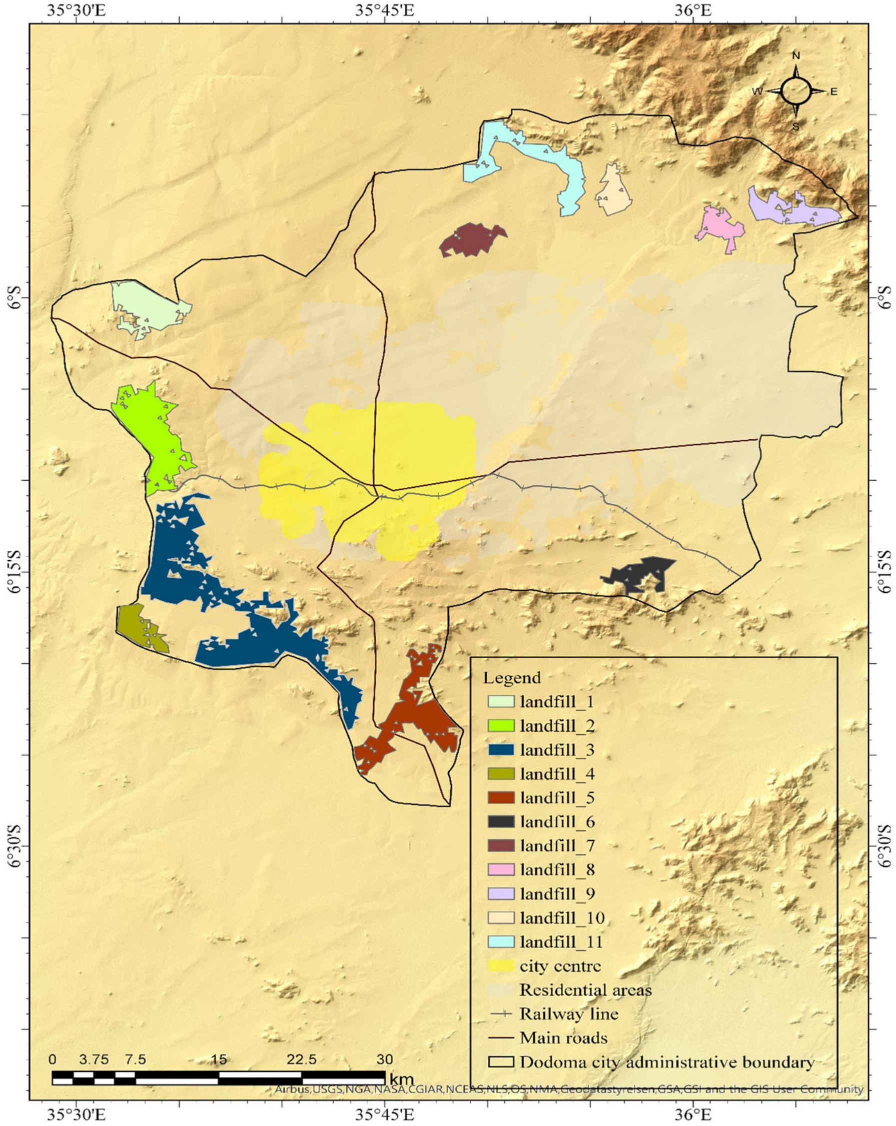


Fig. 8 Candidate landfill sites from residential areas, roads, railway, and the city centre

Table 6 Weights computation for evaluation criteria

Criteria	Size	Distance from residential areas	Weights	%
Size	1	2	0.67	66.67
Distance from residential areas	0.5	1	0.33	33.33

2020). In the current study, landfill sites 2, 3, and 5 are found close to residential areas as compared to other landfill sites hence they are economically highly suitable. However, landfills should not be located near residential areas to prevent human and environmental impacts (Jerie & Zulu, 2017). Thus, in distance-based perspective from residential areas, landfill sites 4, 5, and 10 are highly suitable compared

Table 7 Pairwise comparison matrix of landfill sites based on their size

Size (ha)	LF_1	LF_2	LF_3	LF_4	LF_5	LF_6	LF_7	LF_8	LF_9	LF_10	LF_11	Eigenvector	%
LF_1	1.00	2.00	5.00	0.50	0.25	3.00	0.20	0.30	0.60	0.70	4.00	0.086	8.63
LF_2	0.50	1.00	0.60	5.00	9.00	6.00	4.00	3.00	3.00	0.40	0.80	0.147	14.70
LF_3	0.20	1.67	1.00	3.00	4.00	6.00	7.00	5.00	8.00	7.00	9.00	0.185	18.50
LF_4	2.00	0.20	0.33	1.00	2.00	3.00	2.00	0.50	2.00	0.40	2.00	0.058	5.85
LF_5	4.00	0.11	0.25	0.50	1.00	4.00	3.00	4.00	5.00	6.00	6.00	0.110	11.04
LF_6	0.33	0.17	0.17	0.33	0.25	1.00	3.00	0.40	4.00	4.00	9.00	0.063	6.34
LF_7	5.00	0.25	0.14	0.50	0.33	0.33	1.00	0.40	5.00	0.60	6.00	0.062	6.16
LF_8	3.33	0.33	0.20	2.00	0.25	2.50	2.50	1.00	0.25	0.25	2.00	0.056	5.61
LF_9	1.67	0.33	0.13	0.50	0.20	0.25	0.20	4.00	1.00	9.00	9.00	0.076	7.60
LF_10	1.43	2.50	0.14	2.50	0.17	0.25	1.67	4.00	0.11	1.00	0.25	0.065	6.46
LF_11	4.00	5.00	3.00	0.50	0.17	0.11	0.17	0.50	0.11	3.00	1.00	0.091	9.11
sum	23.46	13.56	10.96	16.33	17.62	26.44	24.73	23.10	29.07	32.35	49.05	1.00	100.00

Whereas LF refers to landfills, 1 to 11 represents the number of landfill sites

Table 8 Pairwise comparison matrix of landfill sites based on distance from residential areas

Distance (km)	LF_1	LF_2	LF_3	LF_4	LF_5	LF_6	LF_7	LF_8	LF_9	LF_10	LF_11	Eigen vectors	%
LF_1	1.00	3.00	2.00	0.25	0.50	2.00	5.00	8.00	3.00	2.00	2.00	0.10	10.09
LF_2	0.33	1.00	0.50	0.33	0.50	2.00	2.00	8.00	0.50	3.00	2.00	0.07	7.00
LF_3	0.50	2.00	1.00	0.30	0.50	0.50	4.00	9.00	2.00	0.33	2.00	0.07	7.03
LF_4	4.00	3.03	3.33	1.00	3.00	5.00	6.00	9.00	7.00	5.00	6.00	0.23	23.15
LF_5	2.00	2.00	2.00	0.33	1.00	4.00	6.00	8.00	3.00	6.00	4.00	0.15	14.66
LF_6	0.50	0.50	6.00	0.20	0.25	1.00	3.00	5.00	2.00	0.50	2.00	0.08	7.53
LF_7	0.20	0.50	0.25	0.17	0.17	0.33	1.00	3.00	0.50	0.33	0.50	0.02	2.41
LF_8	0.13	0.13	0.11	0.11	0.13	0.20	0.33	1.00	0.25	0.33	0.33	0.01	1.28
LF_9	0.33	2.00	0.50	0.14	0.33	0.50	8.00	9.00	1.00	0.50	0.50	0.06	6.14
LF_10	0.50	0.33	3.03	0.20	0.17	9.00	3.03	3.03	9.00	1.00	3.00	0.11	10.99
LF_11	0.50	0.50	0.50	0.17	4.00	0.50	5.00	8.00	8.00	0.33	1.00	0.10	9.72
sum	9.99	14.99	19.22	3.20	10.54	25.03	43.36	71.03	36.25	19.32	23.33	1.00	100.00

Whereas LF refers to landfills, 1 to 11 represents the number of landfills, CR = 0.04 acceptable (Saaty, 1980)

to others as they are far from the residential areas with eigenvectors 0.23, 0.15, and 0.11, respectively (Table 8).

The obtained results lead to an inconsistent decision of siting the best landfill site basing on the aforementioned criteria. Therefore, weights of all identified landfill sites were multiplied by the corresponding criteria's weights (Distance from residential areas and size of the site) and summing their products to remove inconsistent decision making, and ranking landfill sites from the best to worse based on the set criteria (Table 9) as employed in other studies (Sisay et al., 2020).

The current study discloses the best three landfill sites, where landfill sites 3, 5, and 2 are identified as highly suitable sites ranked as first, second, and third with eigenvectors weights of 0.147, 0.122, and 0.121, respectively (Table 9). These sites are selected based on their size and distance from residential areas to avoid the risk of human health and surrounding

Table 9 Weights of the landfill sites and their ranks

Landfills	Size of the sites (ha)				Distance from residential areas (km)				Weights	Weights score (%)	Rank
LF_1	0.086	x	0.667		0.101	x	0.333		0.091	9.117	6
LF_2	0.147	x	0.667		0.070	x	0.333		0.121	12.134	3
LF_3	0.185	x	0.667		0.070	x	0.333		0.147	14.676	1
LF_4	0.058	x	0.667		0.232	x	0.333		0.116	11.615	4
LF_5	0.110	x	0.667		0.147	x	0.333		0.122	12.245	2
LF_6	0.063	x	0.667	+	0.075	x	0.333	=	0.067	6.736	9
LF_7	0.062	x	0.667		0.024	x	0.333		0.049	4.909	10
LF_8	0.056	x	0.667		0.013	x	0.333		0.042	4.170	11
LF_9	0.076	x	0.667		0.061	x	0.333		0.071	7.111	8
LF_10	0.065	x	0.667		0.110	x	0.333		0.080	7.970	7
LF_11	0.091	x	0.667		0.097	x	0.333		0.093	9.317	5
Total									1	100	

environments. On the other hand, landfill sites 8, 7, and 6 are lastly ranked. These sites are nearby to residential areas and small in size as they can be used within a short time (Table 9).

Conclusion

This study signifies an important step in addressing an important gap in identifying and ranking suitable locations for solid waste disposal to enhance green cities in most developing countries. Different influencing criteria from various disciplines including proximity from built-up, surface water, episodic water channels, boreholes, sensitive sites, protected areas, major faults, LULC, lithology/geology, soil type, elevation, slopes, proximity from airport, roads, railway, and earthquake epicentres are integrated into this study. These influencing criteria have been employed in various landfills siting studies elsewhere but in different combinations (Hazarika & Saikia, 2020; Kazuva et al., 2020; Özkan et al., 2020; Rezaeisabzevar et al., 2020; Sisay et al., 2020). However, these criteria apply differently to different areas (Babalola & Busu, 2011; Sadek et al., 2006). Integration of GIS and AHP has kept a high level of accuracy and efficiency in site selection problems globally (Asefi et al., 2020; Şener & Şener, 2020; Yazdani et al., 2020). The overall suitability results depict that 41,177 ha (14.7%) of the study area is determined as highly suitable for landfill site location. The remaining 83,930 ha (30%), 84,305 ha (30.2%), and 53,508 ha (19.1%) of the area are suitable, moderately suitable, and less suitable respectively while 16,683 ha (6%) is under the unsuitable zone. From the highly suitable zone, eleven candidate landfill sites were selected and prioritized using the AHP technique. The final suitability results show landfill sites 3 (10,361.94 ha), 5 (3717.85 ha), and 2 (3535.86 ha) were found to be the most highly suitable sites with eigenvector weight of 0.147, 0.122, and 0.121 respectively. These identified optimal sites minimize environmental and health problems as well as economic and social costs. On the other hand, landfill sites 8, 7, and 6 are lastly considered as they are located near residential areas and are small in size. The existing landfill is partly located in a less to moderately suitable area which was manually sited. The identified sites can be considered for future city planning as they adhere to the Tanzania government environmental management regulations (URT, 2019). In conclusion, the current results can be adopted by city planners, authorities, decision-makers, and other stakeholders to improve solid waste management practices within the capital city in a cost and time-effective way.

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Code availability Available upon request.

Declarations

Conflicts of interest There is no potential conflict of interest.

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