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Optimized landfill site selection for municipal solid waste by integrating GIS and multicriteria decision analysis (MCDA) technique, Hossana town, southern Ethiopia

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ABSTRACT

Improper solid waste disposal has remained the major bottleneck for the socio-economic development particularly in urban and peri-urban areas of Ethiopia. This study was conducted with the prime aim of identifying an optimum municipal solid waste (MSW) management option subsequently selecting the best landfill site in Hossana town using integrated geographical information systems (GIS) and multicriteria decision analysis (MCDA) techniques. Accordingly, GIS integrated with MCDA was used to analyze the relative weight of each criterion and the overall suitability map where ten criteria were considered within their respective constraints. To create a landfill suitability index, environmental and socioeconomic factors such as distance from settlement, land use and land cover, lineament, slope, road, and wind direction/aspect were weighted. Population growth, waste generation rate, and waste volume/year were used to calculate the required landfill size. The study finding revealed that the town's MSW generation rate was 0.45 kg/cap/day, which was within the range of most of Ethiopian urban areas. On the other hand, the total daily and annual MSW generation was found to be 79.58 and 29,047 tonnes, respectively. Moreover, the study's findings revealed that 20.8 % of the solid waste was found was recyclable and the remaining 79.20 % was non-recyclable. Considering the future trend of waste generation, 19 ha of land in the city's Northern and Southern outskirts was chosen as a candidate landfill site with all the necessary suitability analysis. Therefore, optimized landfill site selection and better management system of MSW in urban and peri-urban areas could be achieved by the conjunctive application of MCDA and GIS.

1. Introduction

Municipal solid waste is any substance generated by human and/or animal activities and discarded as worthless or undesired [1]. These days, improper handling and management of municipal solid waste (MSW) is significantly degrading the environmental quality and reducing its aesthetic value thereby becoming the major challenges for governments of mainly developing countries [2]. Moreover, rapid urbanization makes solid waste disposal and management planning more difficult, especially in low-income countries [3]. Recently, MSW and its management is becoming humanity's prime problem and worrisome phenomenon and it is now a serious concern for almost every country on the planet. Moreover, municipal solid waste disposal has shown to be a major public health

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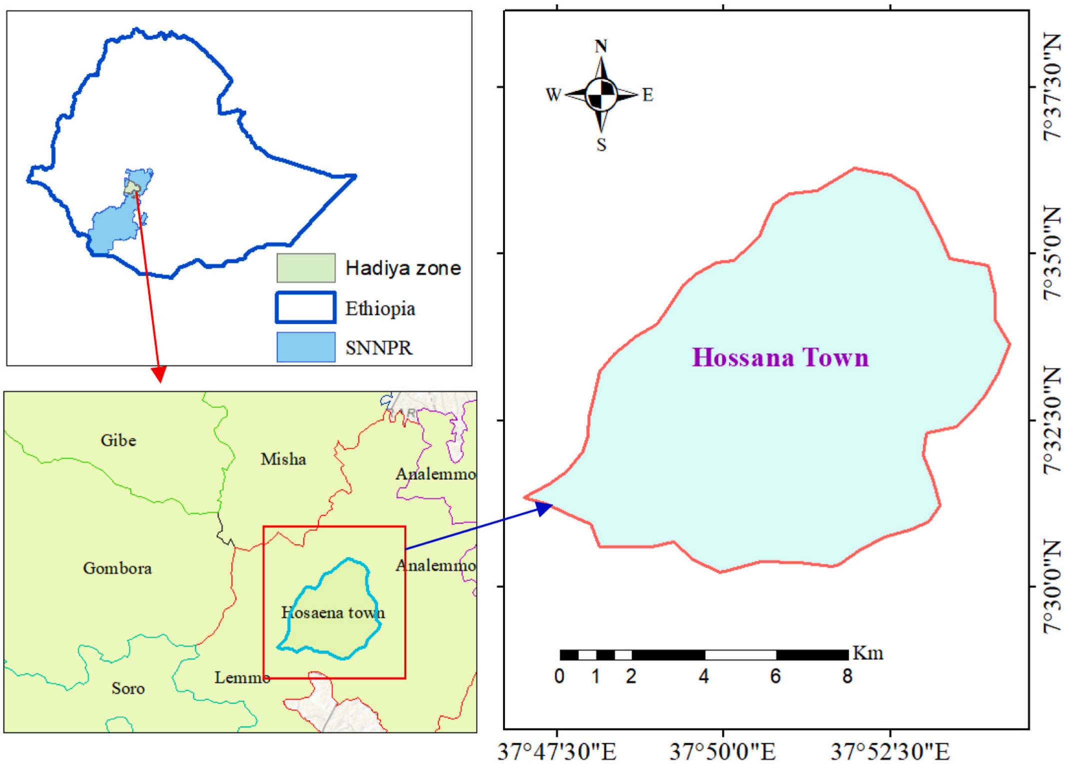

Fig. 1. Study area map.

concern as well as a critical factor influencing the environmental quality of all living things [4] (see Figs. 1, 5–13).

In developing countries, current municipal solid waste management procedures, particularly collection, processing, and disposal, are deemed inefficient. Surprisingly, the indiscriminate dumping of municipal solid wastes near water bodies and low-lying areas, without regard for the environmental impact, is a typical practice in many developing-country towns [5]. Due to the potential for solid waste to harm water, food supplies, land, air, and vegetation, poor waste management poses a significant threat to the well-being of the community particularly those living near dumpsites. As a result of inadequate solid waste management, handling and processing in those countries, the environment is heavily degraded, the ecosystem is reducing its services, and public health is threatened [6].

Landfilling is an environmentally safe and socially acceptable method of disposing of municipal solid waste that also safeguards the environment and public health hazards [7]. The most secure approach to dispose of solid waste is to keep it in landfills that have been properly designed, built, and managed, and where it is safely contained [8]. In this regard, despite the advanced use of GIS for selection of better landfill site is vital, it is almost ignored in many developing countries. GIS and Multicriteria Decision Analysis are tools that play a significant role in helping to solve the issue and for sustainable environmental and public health protection. It contributes for the selection of appropriate disposal sites through the management of a large volume of spatial data. Integration of GIS with multi-criteria decision analysis is used to select an appropriate landfill site by considering a variety of factors and constraints [9].

Despite high rate of urbanization and rapid growth of the population in Hossana town, there is no suitable municipal solid waste disposal site in the area. Besides, the MSW management system is deemed ineffective and traditional and has remained a critical challenge these days as it has social, economic and environmental implications. The prevailing of informal settlements associated with large production of solid waste is also becoming the worrisome phenomenon in the desire of the city for development. This study is therefore intended to change the paradigm on solid waste management and handling thereby assessing and showing approaches for the selection of a suitable site for the dumping of municipal solid waste in the study area, reducing economic, human health, and environmental risks.

2. Materials and methods

2.1. Description of the study area

Hossana town is located in southern nations, nationalities, and people regional state of Ethiopia. It is the administrative and commercial center of the Hadiya Zone. The town is located southwest of the capital Addis Ababa at a distance of 230 Km and 168 Km southeast of the regional capital, Hawassa. It lies between 7° 27′ 00″ to 7° 40′ 00″ N latitude and 37° 41′ 00″ to 37° 56′ 00″ E longitude as illustrated in Fig. 1 below.

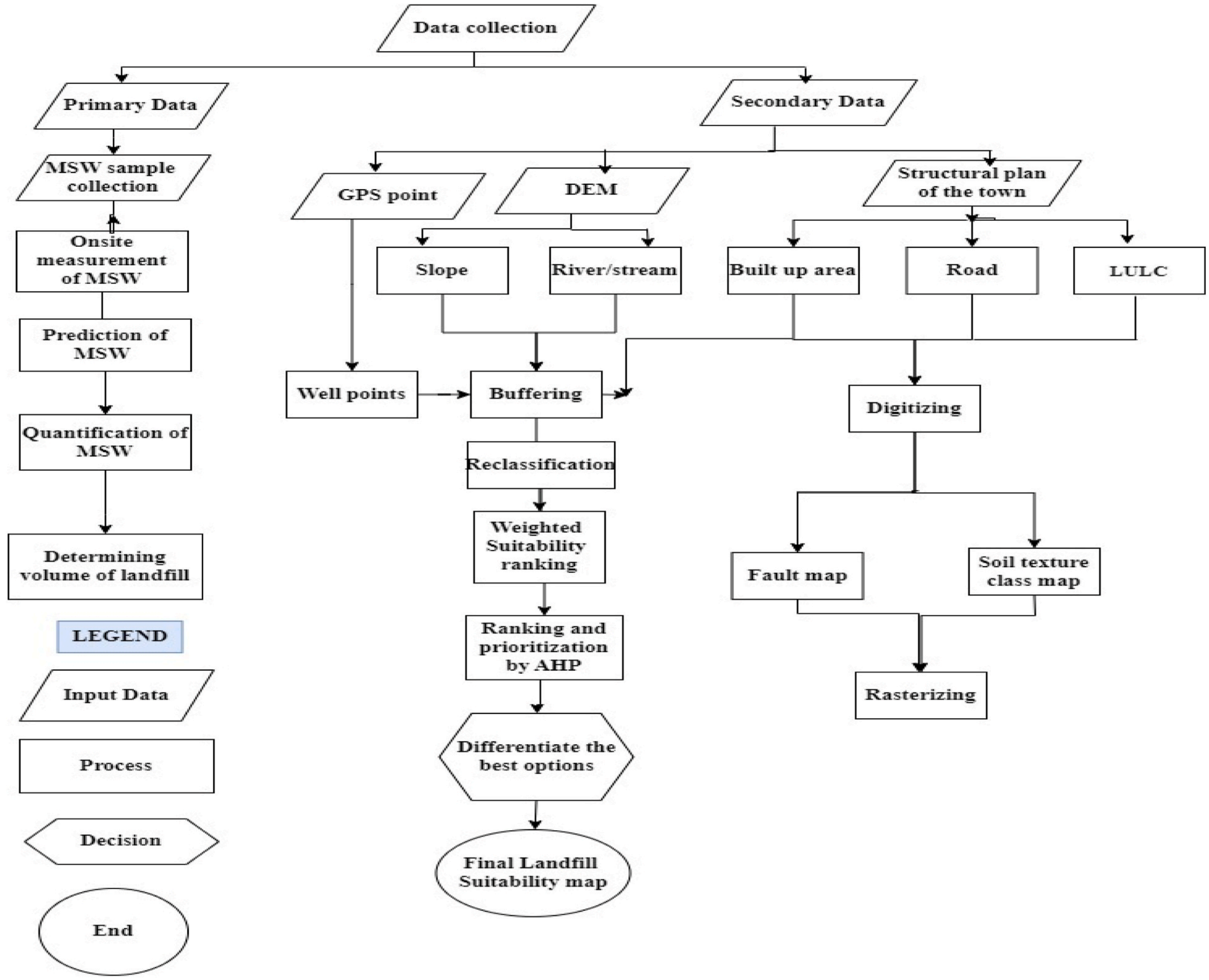

Fig. 2. Conceptual frame work of data collection.

The town has an area of 8945 ha, out of this 4585.48 ha of the town has been master-planned (Hossana town Finance and Economic Development,2013). The total population of Hossana is estimated about 69,957 (CSA, 2016). Hossana has a total area of 89.45 sq.km divided into three sub cities which in turn divided into 6 kebeles, lowest level of administrative structure.

2.2. Sample collection and analysis

2.2.1. Source and type of data

This study comprised a variety of primary and secondary data that has been used to analyze the research, such as images from Landsat 8 were used to represent the characteristics of land-use/land-cover classes. Various factor maps aided in the selection of a suitable disposal site. These included a road network map, soil texture map, river map, building map, airport map, geological map, land-use/land-cover type of the research region, built-up area extracted from the master plan, and DEM used to calculate slope, wind direction and fault of the study area. These data sources were used to acquire the information needed to address the study's purpose and goal. Primary data was obtained from each sub-city's concerned bodies by using different mechanisms such as interviewing, focus discussion group and observing the site whereas secondary data was collected from books, reputable journals, sanitation and respective government offices (Fig. 2).

2.2.2. Sample size determination and quantification

In this study stratified sampling approaches was used. There were three sub-cities as strata for the town's six kebele. The kebeles that were sampled has been drawn at random from each stratum. The number of samples within each kebele was calculated by using the proportional percentages of each stratum. To identify the participating selected sample respondents in the current study, they were divided into two groups: residential and non-residential, which were categorized as 90 % and 10 % of the total number of housing

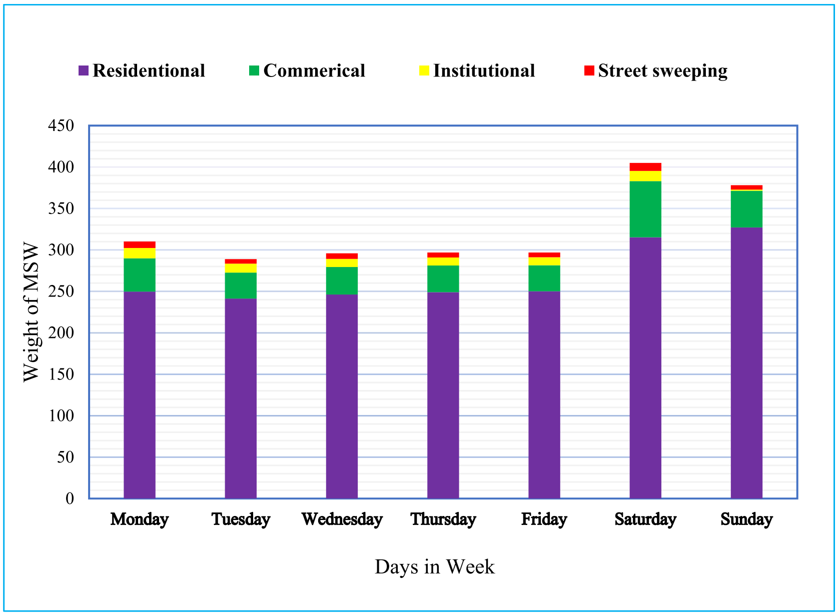

Fig. 3. Municipal solid waste generation.

units, respectively CSA (2016). The sample size (n) of participating households was determined by using Kothari's formula.

$$n = \frac{Z^2P(1\text{-}P)N}{e^2(N\text{-}1) + Z^2P(1\text{-}P)} \tag{1}$$

Where; n = The required number of sample; P=Housing unit variable (Residential houses which are 90%of N); Q = Non-residential houses which is 10 % of N (1-P); N = Total number of households; Z = The desired confidence level at 95 % interval equal to 1.96; e = the expected error of 3 % which is equal to 0.03.

According to data obtained from Hossana Municipality planning and economic development office (2022), there are about 26,825 households within six administrative kebeles.

$$n = \frac{(1.96)^2(0.05)(1\text{-}0.05)(26,825)}{(0.03)^2(26,825\text{-}1)+(1.96)^2(0.05)(1\text{-}0.05)} = 202$$

In this study, a total number of 202 households were considered to collect all the necessary data by using Equation (1) above.

2.2.3. Physical composition and quantification of solid wastes

Samples of the solid waste was collected for consecutive seven days. Besides, in order to have a representative sample from each household and in consideration of differences in waste generation between days, two plastic bags labeled with the respective house number were given for biodegradable and non-degradable solid waste for each household. The bag distribution was based on the prior knowledge of the life style of each house. The samples were then transported to the working area by using horse-driven carts for further processing. All the collected samples were segregated at working site.

$$DSWGR = \frac{\text{total solid waste generation rate in 7 days}}{\text{7 daysx sample size}} \tag{2}$$

$$PCDSWGR = \frac{\text{total solid waste generation rate in 7 days}}{\text{7 day} * \text{total family size in household}} \tag{3}$$

$$ASWGR = DSWGR * 365\ \text{days} \tag{4}$$

Where: DSWGR- Daily solid waste generation rate.

PCDSWGR- Per capita per day solid waste generation rate.

ASWGR- Annual solid waste generation rate.

Equations (2)–(4) are applied to calculate the daily, weekly, monthly and yearly solid waste generation and after all to fix the design period of the landfill.

2.3. Criteria for selecting potential landfill site

To identify the best solid waste disposal location meeting requirements of government regulations and minimizing economic, environmental, health, and social cost, ten targeted criteria were evaluated, namely; slope, surface water, geology, built-up area, road networks, soil, faults, land use land cover, ground water depth, protected areas, and elevation to determine the appropriate location of the solid waste landfill site. All the criteria were evaluated based on the national and/or international standards for the respective criteria.

2.4. Landfill site selection approaches

The optimum landfill site selection approach in this study was performed in consideration of recommending solid waste disposal sites that meet environmental criteria while minimizing economic costs. For this, a variety of GIS spatial analytic procedures were used to meet the suggested goal of the current study such as rasterizing, georeferencing, digitizing, buffering, and overlay analysis. Based on specific evaluation criteria, the study approach integrates GIS and MCE techniques using Analytical Hierarchy Process (AHP).

All available input datasets were georeferenced and saved in a GIS environment, from which various characteristics were generated by utilizing GIS spatial analytic methods. The weight average for each criterion is calculated using AHP. To standardize or normalize the values of all criteria for comparison, each resulting dataset were rasterized and reclassified to a common measurement scale. Then, using weighted overlay analysis, all standardized criteria were integrated to create a thematic map of the study area identifying potential landfill sites. To offer an appropriate landfill site map, GIS spatial analysis tools were utilized to generate the identified ten primary landfill siting criteria as layers, each criterion consisting of a database of a digital map prepared within the ArcGIS software [10].

2.4.1. Thematic map preparation

A thematic map is a type of map that describes the geographic pattern of a particular subject matter (theme) in a geographic area. This usually involves the use of map symbols to visualize selected properties of geographic features that are not naturally visible. In this study, geographic data in the form of a map were generated by digitizing, rasterizing, reclassifying, overlaying, and buffering with the required criteria as an input for suitability analysis. Accordingly, slope, road, lineament, soil type, aspect, land use land cover, groundwater well depth, river, protected areas and built-up area maps were generated in this study.

2.4.2. Digitizing

This function of GIS converts the base map of the area into digital map to use in GIS environment. This is done by using on-screen digitizing by encoding the spatial coordinates of the features on the map. In this study, it was used to digitize boundaries of the town, road network, and settlement area that exist in the study area from the structural plan.

2.4.3. Buffering of criteria

Buffering is the technique of establishing numerically distanced regions from a feature. In this study this procedure was determined by taking into account geographic aspects of the Hossana town as well as numerous literatures to reclassify regions from a landmark. The buffering analysis in this study also comprised the well depth, protected area, road, built-up area, power tension line and river stream.

2.4.4. Reclassification of criteria's

Landfill site selection criteria were divided into two categories: limitations and factors. Constraints (limited) relate to areas that are inappropriate for landfill sites due to the possibility of adverse effects on human health and the environment, as well as the expensive cost of land [11]. As a result, in any geographic area, several factors are considered in the mapping of optimal disposal site selection. The following factors were evaluated in the current study: groundwater well depth, slope, river, road, soil type, land-use/land cover, lineament, aspect/wind direction, protected areas, and built-up area. The factor maps were classified based on their applicability in the disposal site selection process. Generally the factors were reclassified into five suitability classes by numerical value, namely unsuitable (restricted), low suitable, moderately suitable, highly suitable and very highly suitable, as illustrated in each criteria of results and discussion part.

2.5. Landfill site selection techniques

2.5.1. Application of GIS for landfill site selection

GIS is a computerized system for storing, retrieving, manipulating, analyzing, and mapping geographical data. This allows data saved in one form to be combined with data entered and stored in another form. The use of a location referencing system is the primary component of a GIS, allowing data about a single location to be studied in connection to other locations. Furthermore, using proximity analysis, also known as buffering and overlay, maps were constructed that indicate the places that meet the selected criteria [12]. Nishant et al. (2010) further emphasized the capacity of GIS to connect spatial data (maps, aerial pictures, satellite images) with other quantitative, qualitative, and descriptive information databases, aiding suitability analyses such as site selection.

According to Nishant et al. (2010), GIS plays an important role in solid waste management since many aspects of its planning and operations depend solely on spatial data. One of the advantages of GIS is its ability to select dump sites. As Sumiani et al. (2009)

Table 1
Weight and Volume of daily/person solid waste collected from HH at Hosanna town by Income level among the kebeles.

Name of kebele	Weight of Daily/person MSWG rate by Income level in (kg)			Volume of Daily/person MSWG rate by Income level (m^3)		
	High	Medium	Low	High	Medium	Low
Lich- amba	0.62	0.45	0.37	0.00138	0.00126	0.00122
Sech-duna	0.38	0.37	0.32	0.00036	0.00031	0.00026
Bobicho	0.57	0.56	0.50	0.00224	0.00214	0.00211
Jello-naramo	0.49	0.41	0.40	0.00136	0.00119	0.00104
Heto	0.44	0.43	0.34	0.00070	0.00065	0.00054
Arada	0.59	0.42	0.39	0.00022	0.00017	0.00015

mentioned, GIS is commonly utilized in landfill site selection to achieve the combination of defined criteria to develop suitability maps.

As a result, GIS provides the spatial analytical capabilities to rapidly identify parcels of land that are inappropriate for landfill sites [13], reducing the cost and time of the siting process. GIS screening of inappropriate land is followed by the use of an MCDA to determine the most acceptable sites based on information provided by regional experts and additional criteria [14].

2.5.2. Analytical Hierarchical process

Analytical Hierarchy Process (AHP) is a typical MCDA tool and technique for analyzing and supporting decisions in which multiple and competing objectives are involved and multiple alternatives are accessible. The method is founded on three principles: decomposition, comparison assessment, and priority formulation. AHP technique subdivides the problem into a hierarchy of sub-problems that can be more usually developed and subjectively evaluated. The AHP is a decision-making technique that analyzes and supports decisions with many, even competing for objectives [15]. [16] introduced that Both GISand AHP procedures are used to obtain potential site selection. The GIS is used to modify and present spatial data, whereas the AHP is used to rate possible landfill sites based on a range of factors.

The integration of GIS and AHP allows for the analysis of a variety of required qualitative and quantitative parameters for landfill site selection. Subjective evaluations are transformed into numerical values that are ranked on a numerical scale [17]. It is achieved by reducing a complex problem into several lesser problems in the form of a decision hierarchy. Following that, a pair-wise comparison matrix for each element is generated. A pair-wise comparison matrix of each element inside each level is created, which may then be weighed against one another and within each level. The AHP is frequently used to examine the relative applicability of a limited number of alternatives for the entire process.

3. Results & discussion

3.1. MSW generation rate

The MSW assessment in this study revealed that, the generation rate significantly vary between varying income levels, households, and economic experiences. Details of the MSW generation rates for various kebele and income level is shown on Table 1.

3.1.1. Daily MSW generation rate by income level by weight

As shown in Table 1 the daily MSWG rate of Hosana town in the amount of household waste generated per capita was determined. The highest daily solid waste generated per capita found to be 0.62 kg/person/day for high income level at Lich-amba kebele. However, the lowest daily solid waste generated from Sech-Duna kebele was 0.32 kg/person/day for low-income level. The daily average generated solid waste from high, middle and low-income level in study area were 0.515 kg/person/day, 0.44 kg/person/day and 0.387 kg/person/day respectively. The result showed that the trend of waste generation per capita/day increases as the monthly income increases owing from the fact that the consumption rate has increased in the town.

This study agreed with the result obtained from the research conducted in South Africa which was 0.41 kg/person/day, 0.74 kg/person/day and 1.29 kg/person/day generation rates per income level for low, middle and high respectively [18]. According to another survey conducted in Botswana, low-income households on weekends had a minimum production of 0.038 kg/person/day and high-income households on weekends had a maximum production of 0.364 kg/person/day [18]. Generally, the lowest solid waste generation record was observed in Sech-duna kebele for all income levels for Hosanna town.

3.1.2. Daily MSW generation rate by income level by volume

The daily municipal solid waste generation rates of Hossana town at HH waste generation per capita is indicated in Table 1. The highest daily solid waste generated per capita found to be 0.00224 m^3/person/day for high income level at Bobicho kebele whereas the lowest daily solid waste generated from Arada kebele was 0.00015 m^3/person/day for low-income level. From the tabular data, it can be seen that for the high, medium, and low-income levels, MSW produced in Arada Kebele have a smaller volume (m^3) than other Kebeles of the city due to living standard of the residents living there.

3.1.3. Municipal solid waste Categorizations of HH by weight

The daily average municipal solid waste generation rates of Hosanna town at HH by category waste generation per capita is shown

Table 2
Daily per capital MSWG rate by category for Hosanna town by weight(kg).

Kebeles	Food	Plastic	Glass	Textile	Paper	Metal	Fine particles	Miscellaneous
Lichamba	0.1649	0.0326	0.0022	0.0409	0.0001	0.0001	0.1651	0.0409
Heto	0.1705	0.0351	0.001	0.0073	0.0001	0	0.1651	0.0409
Arada	0.1955	0.0373	0	0.0198	0.0003	0	0.2386	0.089
Jalo Naramo	0.394	0.0549	0.0004	0.0058	0.0007	0	0.0093	0.0007
Sechduna	0.1672	0.0318	0	0.0263	0.001	0.0025	0.0519	0.0313
Bobicho	0.4006	0.0501	0.0004	0.0026	0.0001		0.0042	

Table 3
Daily MSWG rate by category by weight in (kg).

Source of waste (kg)	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Residential	249.7	241.3	246.2	248.9	250.1	315.2	327.1
Commercial	40.2	31.3	33.2	32.3	31.3	67.8	44.2
Institutional	12.4	10.8	9.8	9.6	9.7	12.3	1.5
Street sweeping	7.8	5.4	6.7	6	5.8	9.6	5.2
Total	310.1	288.8	295.9	296.8	296.9	404.9	378

Table 4
Forecasting solid waste generation rate of study area for the coming 15 years.

Year	Population	MSW (10^3 ton/year)	Recyclable MSW (ton/yr.)	Non-recyclable MSW (ton/yr.)
2022	177944	29.33	6100.64	23229.36
2023	189894	31.3	6510.4	24789.6
2024	202647	33.06	6876.48	26183.52
2025	216257	35.28	7338.24	27941.76
2026	230781	37.65	7831.2	29818.8
2027	246280	40.18	8357.44	31822.56
2028	262820	42.88	8919.04	33960.96
2029	280470	45.76	9518.08	36241.92
2030	299306	48.83	10156.64	38673.36
2031	319408	52.11	10838.88	41271.12
2032	340859	55.61	11566.88	44043.12
2033	363751	60.02	12484.16	47535.84
2034	388180	64.05	13322.4	50727.6
2035	414250	68.35	14216.8	54133.2
2036	442070	72.94	15171.52	57768.48
2037	471759	77.84	16190.72	61649.28

in Table 2. The highest daily food (organic) waste generated per capita was 0.4006 kg/capita/day and 0.394 kg/capita/day at Bobicho and Jalo-naramo kebele, respectively. However, the lowest daily food (organic) waste generated per capita was 0.165 kg/capita/day and 0.1672 kg/capita/day at Lich-amba and Sech-Duna, respectively.

The maximum quantity of waste generated was during the weekends is 404.9 kg/day of waste was collected on Saturday as illustrated in Table 3. This could possible be due to the local market activity which lays on Saturday. Besides, many of the residents stay at home during these weekends and produce large quantity of solid wastes. As a result, residential and commercial waste generation were high. However, institutional establishments relatively generated very small quantity of solid waste. These findings are similar to previous studies which are conducted by Ref. [19].

3.2. Prediction of municipal solid waste generation and population forecasting

Before forecasting the amount of solid waste generated in the town, it is necessary to first assess the generation rate and characterize the solid waste of the research area by collecting a sample size from selected households. For the stated design period, the future municipal solid waste generation has been forecasted for the design period of fifteen years. And also to design landfill size it is mandatory to forecast population number of the study area. Because as number of population increases solid waste generation also increases.

The quantity of waste generated has been calculated as shown in the formula below,

$$Q = (\text{Per capita generation rate of waste} \ * \ \text{Number of Population}) \tag{5}$$

In this study the future population was forecasted by using Central statistical authority (CSA) formula.

Table 5
Criteria adopted for landfill site selection and their status.

Criteria	Parameter	Level of suitability	RW	Area (ha)	% of total area
Proximity to roads	0–400	Unsuitable	1	5814	65
	401–800	LS	2	1567	17.52
	801–1200	MS	3	843	9.42
	1201–1600	HS	4	631	7.05
	>1600	VHS	5	90	1.01
Distance from settlement (m)	0–700	Unsuitable	1	6098	68.17
	701–1500	LS	2	1818	20.32
	1501–2200	MS	3	659	7.37
	2201–3000	HS	4	315	3.52
	>3000	VHS	5	55	0.61
Slope (%)	0–5	VHS	5	2954	33.02
	5.1–10	HS	4	2712	30.32
	10.1–15	MS	3	1986	22.2
	15.1–20	LS	2	904	10.11
	>20	Unsuitable	1	389	4.35
Distance from river (m)	0–500	Unsuitable	1	3713	41.51
	501–1000	LS	2	1727	19.31
	1001–1500	MS	3	1608	17.98
	1501–3000	HS	4	1450	16.21
	>3000	VHS	5	447	5
Distance from Well (m)	0–500	Unsuitable	1	357	3.99
	501–800	LS	2	785	8.78
	801–1200	MS	3	724	8.09
	1201–2000	HS	4	617	6.9
	>2000	VHS	5	6462	72.24
Aspect	East	Unsuitable	1		
	Flat, northeast	LS	2		
	south east	MS	3		
	West	HS	4		
	South west/south	VHS	5		
Soil type	Eutric Cambisoil	Unsuitable	1	1282	14.33
	Chromic Cambisoil	MS	2	3797	42.45
	Leptosols	HS	3	3866	43.22
Distance from protected areas (m)	0–500	Unsuitable	1	711	7.95
	501–1000	LS	2	1154	12.9
	1001–1500	MS	3	1140	12.74
	1501–3000	HS	4	3264	36.49
	>3000	VHS	5	2676	29.92
Lineament (m)	0–500	Unsuitable	1	2247	25.12
	501–1000	LS	2	2973	33.24
	1001–2000	MS	3	2891	32.31
	2001–3000	HS	4	592	6.62
	>3000	VHS	5	242	2.71

RW= Relative Weight; LS = Least suitable; MS = Moderately suitable; HS = Highly suitable; VHS = Very highly suitable.

$$Pn = Poe^{kn} \tag{6}$$

Where P_n is The number of population at nth decade.

P_o is initial population.

K is growth rate (%)

n is number of years.

Volume of landfill.

The design capacity of the landfill, which is the maximum amount of waste that the landfill can ultimately accept. The volume of the landfill will be calculated as the formula below.

$$V = (\text{cumulative quantity of waste} \ / \ \text{Density}) \tag{7}$$

MSW generation = 0.45 kg/capita. day.

Generation rate = 79.58 ton/day.

Volume required/day = 455,364 m^3/yr.

Area required/yr = (1247.6 m^3/day)*(365 day/yr)/(4.5 m) = 101,194 m^2/yr.

Area required/day = 277.25 m^3/4.5 m = 61.61 m^2/day With an allowance of 30 % is employed, area requirement becomes: 80.09 m^2/day and 29234.5 m^2/yr (**by using** equations (5)–(7)).

As illustrated in Table 4, the total amount of solid waste generated in Hossana town was found to be 77, 840 tones/year out of which 79.20 % of the total solid waste was non - recyclable and dumped in landfill whereas the remaining 20.80 % of the total waste

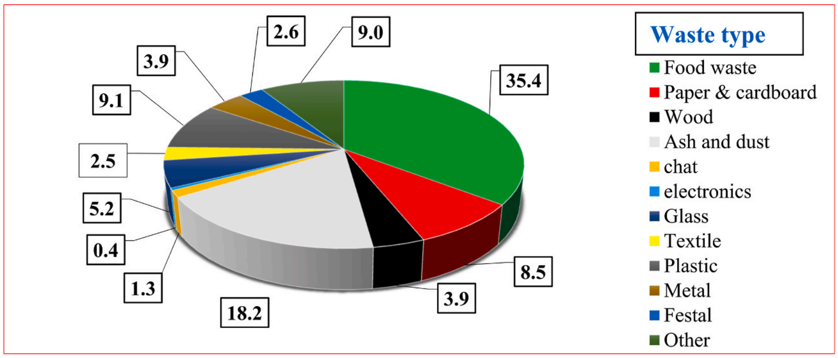

Fig. 4. Composition of municipal solid waste.

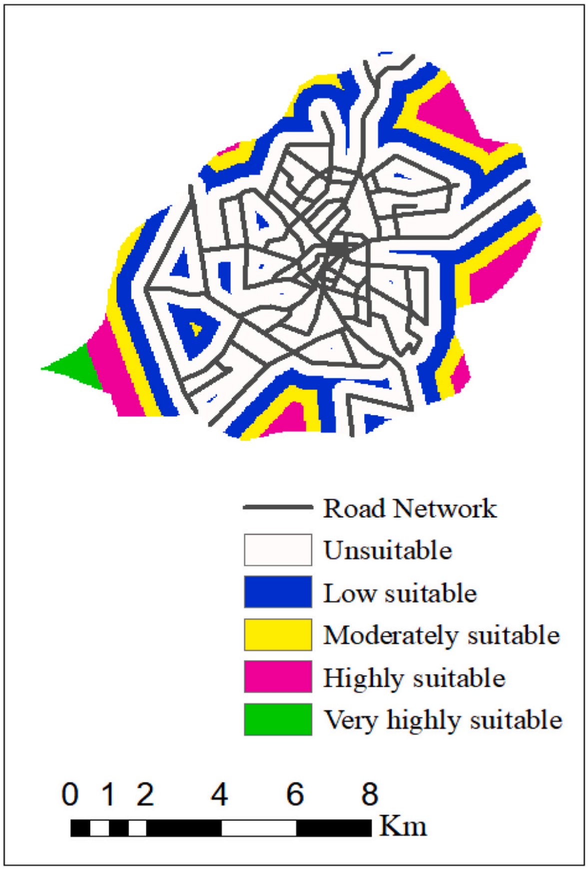

Fig. 5. Road suitability map.

was recyclable. Accordingly, 16, 190.72 tones/year is recycled or reused for various purposes as materials such as glass, plastic, festal, and metal and 61, 649.28 tones/year non – recyclable solid wastes at the end of the design period. As a result, it contributes to reducing the amount of waste disposed of at a landfill site and extending the landfill site's design period. The criterion to select optimized landfill site selection with their respective availability were shown in Table 5.

The current study also revealed that food waste accounted 35.8 % of the total MSW as illustrated in Fig. 4 above (see Fig. 3). However, the findings of this study was slightly higher than those obtained in other cities of the country such as Sawla 34.81 % [20], Debre Berhan 33 % [20], Wolkite 25.53 % [21], and lower than Laga Dadi 37.7 % [22] and Wolaita Sodo 59.5 % [23]. According to this study findings and other comparable studies conducted in urban developing countries, food waste has a large dominance of biodegradable solid waste because it is the most commonly used unprocessed food. In contrast, high-income countries produced a large amount of non-biodegradable waste because they consume packaged goods the majority of the time [24].

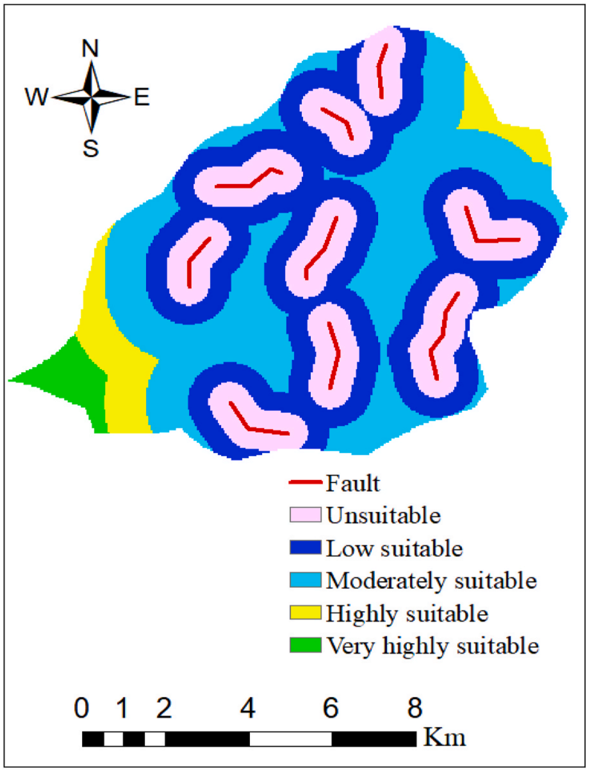

Fig. 6. Lineament suitability map.

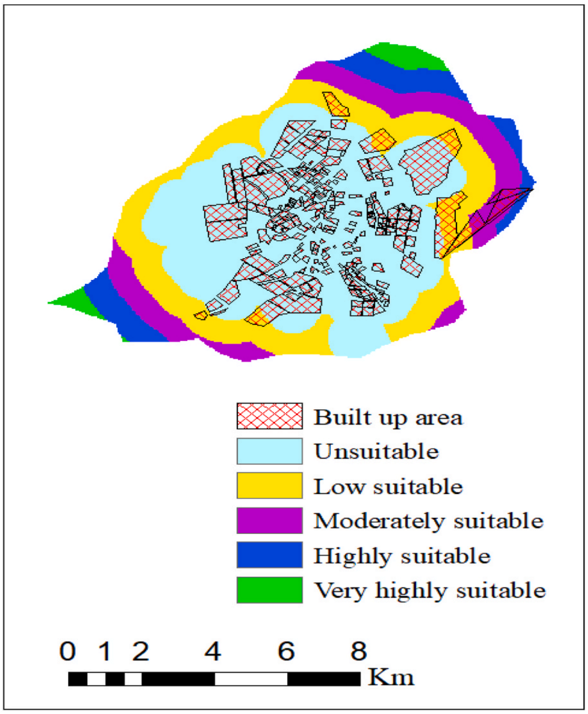

Fig. 7. Settlement suitability map.

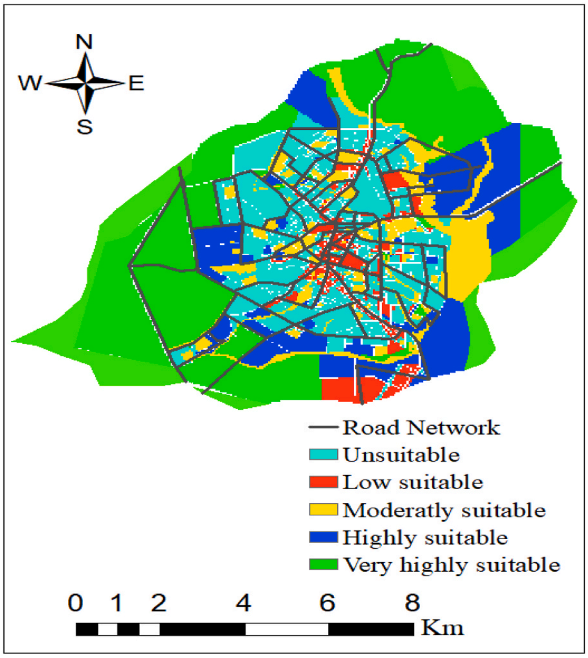

Fig. 8. Land use land cover.

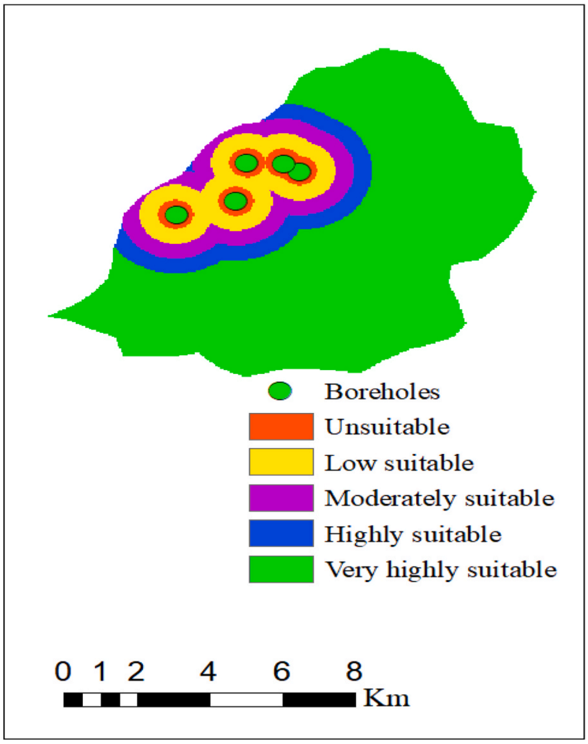

Fig. 9. Well suitability map.

3.3. Solid waste disposal site suitability analysis

Comprehensive aspects must be considered when analyzing suitability of the new planned solid waste disposal site. These primarily include public health concerns, environmental issues, the topography of the area, geology, the land availability of the disposal site in

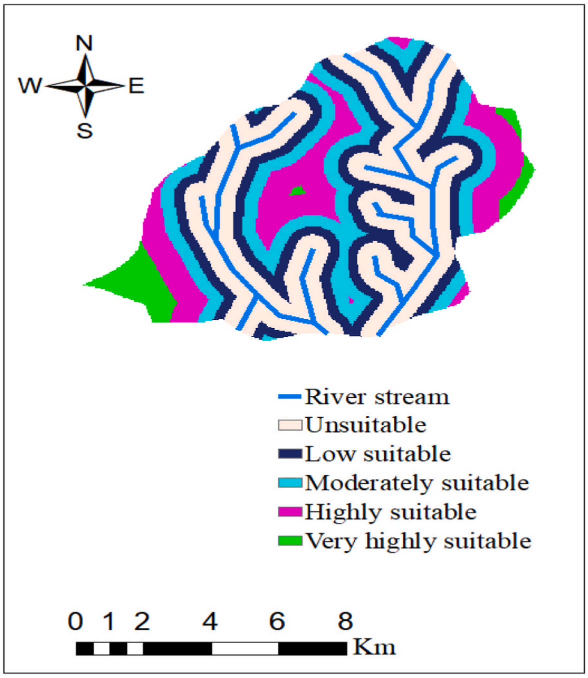

Fig. 10. River suitability map.

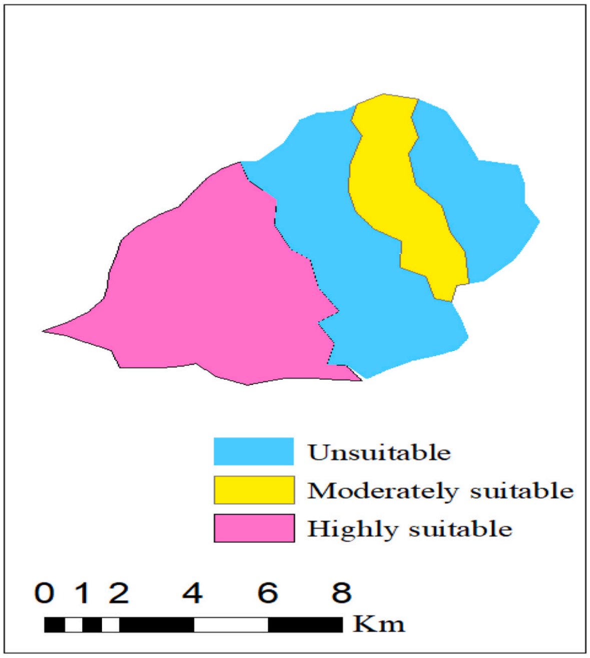

Fig. 11. Soil type suitability map.

the area to cover the waste generated, proximity to built-up areas, proximity to road networks, cost of the current and future land-use area, river, groundwater well depth, soil type [25].

While deciding where to put solid waste, environmental factors such as soil permeability and geology, hydrological factors such as distance from streams and rivers, and topographic factors such as slope, elevation and land uses are all important. The weighting assignment analysis showed that factors related to ground water and surface water, soil permeability, proximity to wells, and streams and rivers, are more important than the other factors because they are critical in preventing leachate from contaminating water. The

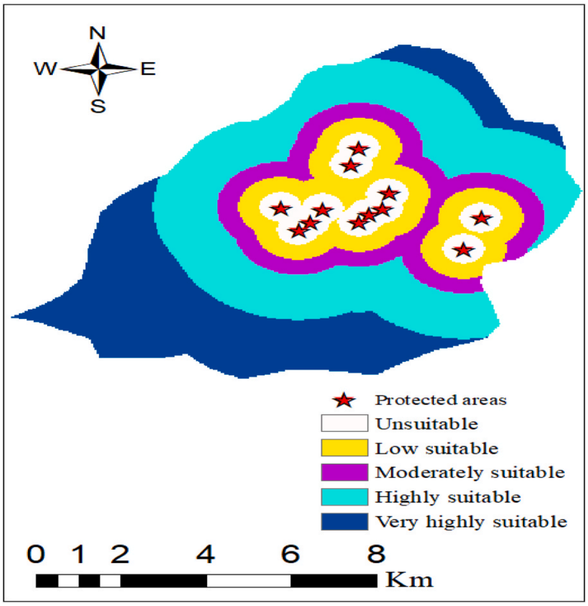

Fig. 12. Protected map.

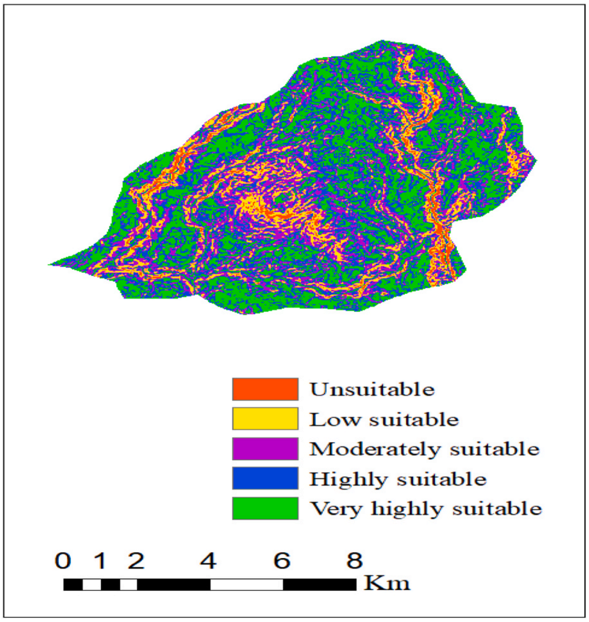

Fig. 13. Slope suitability map.

weighted linear combination result revealed four classes of suitability level. These are in the following order: unsuitable, less suitable, moderately suitable, and highly suitable. This implies that none of the ten (10) criteria considered are particularly well suited. Unsuitable areas include densely built-up and vegetated areas, steep slopes (greater than 15 %), areas near to roads, areas near to groundwater wells, and rivers and streams.

The proposed candidate landfill sites can be carefully managed, such as by lining the waste disposal base, to reduce their negative effects on the environment and public health (see Fig. 14). The majority of the most suitable waste disposal sites were located in the North-East and South-West peripheries of the town as illustrated in Fig. 15. Furthermore, it is prohibited to dispose the solid waste in the town's central and North western parts of the study area, as these areas are thought to be a source of groundwater for the entire town and its surroundings (see Fig. 16).

In order to implement a pair wise comparison in the matrix, every alternative can therefore be assessed in terms of the decision

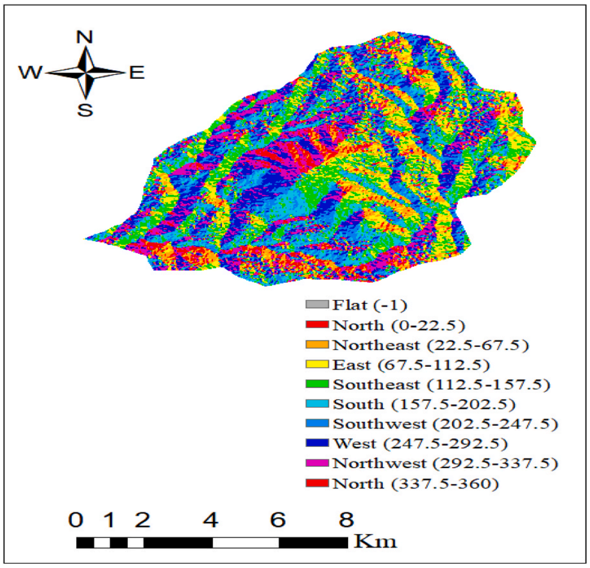

Fig. 14. Prevailing wind direction (Aspect).

Table 6
Pair-wise comparison matrix by using AHP.

Criteria	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
Built-up (A1)	1	0.25	0.25	0.33	0.17	2	0.5	0.2	0.2	2
Land use (A2)	4	1	2	2	0.33	5	4	0.5	0.5	5
Lineament (A3)	4	1/2	1	2	0.25	5	3	0.33	0.33	5
Well (A4)	3	1/2	1/2	1	0.25	4	3	0.33	0.33	4
Road (A5)	6	3	4	4	1	7	5	2	2	7
Slope (A6)	1/2	1/5	1/5	1/4	1/7	1	0.33	0.17	0.17	1
River (A7)	2	1/4	1/3	1/3	1/5	3	1	0.25	0.25	3
Protected Area (A8)	5	2	3	3	1/2	6	4	1	1	6
Soil type (A9)	5	2	3	3	1/2	6	4	1	1	6
Aspect (A10)	1/2	1/5	1/5	1/4	1/7	1	1/3	1/6	1/6	1
Sum	31	9.9	14.48	16.17	3.49	40	25.17	5.95	5.95	40

A1- Built up; A2 - Land use; A3 – Lineament; A4 – Well; A5 – Road; A6 – Slope; A7 – River.
A8 - Protected Area; A9 - Soil type; A10 – Aspect.

Table 7
Normalized Pair-wise comparison matrix for site selection criteria.

Criteria	A1	A2	A3	A4	A6	A7	A8	A9	A10	Sum	cr wt	% Wt
Built-up (A1)	0.03	0.03	0.02	0.02	0.05	0.02	0.03	0.03	0.05	0.33	0.03	3.3
Land use (A2)	0.13	0.1	0.14	0.12	0.13	0.16	0.08	0.08	0.13	1.16	0.12	11.64
Lineament (A3)	0.13	0.05	0.07	0.12	0.13	0.12	0.06	0.06	0.13	0.93	0.09	9.25
Wells (A4)	0.1	0.05	0.03	0.06	0.1	0.12	0.06	0.06	0.1	0.75	0.07	7.47
Road (A5)	0.19	0.3	0.28	0.25	0.18	0.2	0.34	0.34	0.18	2.53	0.25	25.28
Slope (A6)	0.02	0.02	0.01	0.02	0.03	0.01	0.03	0.03	0.03	0.25	0.03	2.26
River (A7)	0.06	0.03	0.02	0.02	0.08	0.04	0.04	0.04	0.08	0.46	0.05	4.65
Protected Area (A8)	0.16	0.2	0.21	0.19	0.15	0.16	0.17	0.17	0.15	1.69	0.17	16.95
Soil type (A9)	0.16	0.2	0.21	0.19	0.15	0.16	0.17	0.17	0.15	1.69	0.17	16.95
Aspect (A10)	0.02	0.02	0.01	0.02	0.03	0.01	0.03	0.03	0.03	0.23	0.02	2.26
Sum	1	1	1	1	1	1	1	1	1		1	100

criteria, and each criteria can be estimated by its weight (relative scale of importance). The values of (aij) are used to represent the performance values in the rows and columns of the matrix when (i = 1, 2, 3, …, m) and (j = 1, 2, 3,.., n) are used as the inputs. Using the equation below, the lower diagonal triangle of the matrix is filled with the comparison criteria values, and the upper diagonal triangle of the matrix is filled with the reciprocal values of the upper diagonal.

$$aji = {}^{1}/_{aij} \tag{8}$$

Table 8
Consistency of criterion.

Criteria	Sum	Criteria weight	Ratio (sum/criteria weight)
Built-up	0.33	0.03	10.1
Land use	1.25	0.12	10.72
Lineament	0.97	0.09	10.52
Wells	0.77	0.07	10.37
Road	2.7	0.25	10.66
Slope	0.25	0.03	10.19
River	0.47	0.05	10.08
Protected Area	1.82	0.17	10.75
Soil type	1.82	0.17	10.75
Aspect	0.23	0.02	10.19
sum			104.35

Eigen values in each row was normalized to determine the priority vector or AHP weight (divided by their sum).

Table 9
Random inconsistency indices for different values of (n) [15].

n	1	2	3	4	5	6	7	8	9	10	11	12	13
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56

Since the number of criteria in this study is 10, so the value of RI in column 10 has been taken as 1.49.

Table 10
The location for optimum landfill sites.

Landfill site	Easting	Northing
Site-1	372700	841165
Site-2	379545	838202
Site-3	378315	835713
Site-4	371012	838322

Weights computation: Weights computation consists of three steps (see Table 6). The first step is to add the values in each column of the matrix. Then, divide each element in the matrix by its column total sum (the resulting matrix is referred to as the normalized pairwise comparison matrix) as illustrated in (Table 7). The average of the elements in each row of the normalized matrix should then be computed by dividing the sum of normalized scores for each row by the number of criteria. These averages estimate the relative weights of the criteria under consideration (Table 8) (see Table 9).

$$\lambda_{max} = \sum \text{ratio}/\text{numberof criteria}$$

$$\lambda_{max} = 104.35/10 = 10.435$$

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

$$CI = \frac{10.435\text{-}10}{10\text{-}1}$$

$$CI = 0.05$$

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

$$CR = \frac{0.05}{1.49} = 0.03 < 0.1\text{.......ok!}$$

Based on the suitability analysis of each criteria, pairwise comparison method was performed for weightage analysis of each criterion using AHP. The Consistency ratio (CR) values of all the comparisons were 0.03 which is less than 0.1, suggesting that the weights obtained are consistent. The results of the pairwise comparison used to obtain priorities between the economic criteria reveals that the proximity from road is the most important criterion with a relative weight of 25 %, followed by the socially valuable area criterion having relative weight of 17 %. The land use land cover criteria have relative weight of 12 %, distance to settlement 3 %, distance from river 5 % and distance from ground water well has relative weight of 7 % (Table 8).

Since the consistency ratio was 0.03 and it is less than 0.1, the pairwise comparison was reasonably consistent.

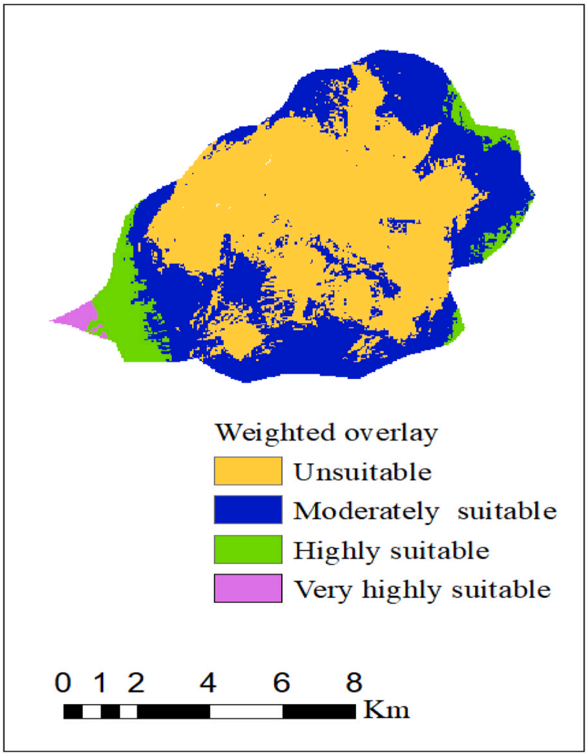

Fig. 15. Weighted overlay map.

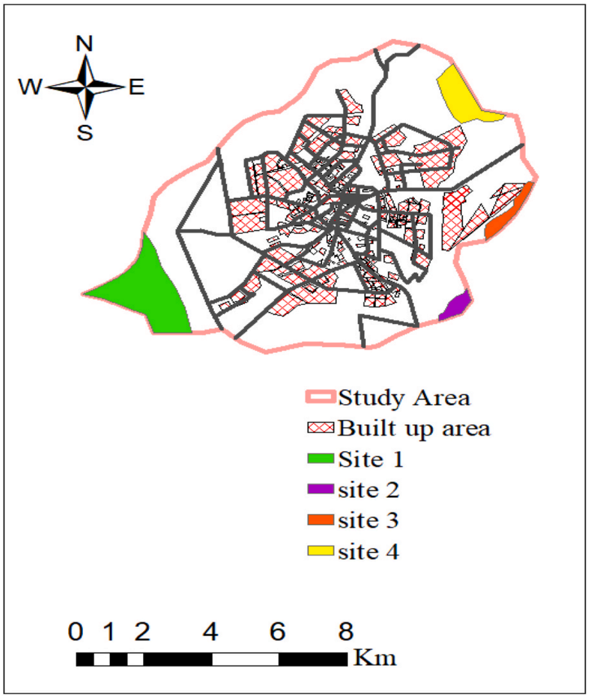

Fig. 16. Candidate landfill sites.

3.4. Evaluating selected candidate landfill sites

The candidate landfill sites are listed in Table 10, along with their location and level of suitability. Therefore, the determining factors used to evaluate potential landfill sites to choose the best suitable sites are the site's size, distance from nearby settlements, and distance from the town center. Because of this, larger-sized plots of land that can be used for at least fifteen years are preferable to smaller-sized plots in order to reduce the cost of site selection, design, and closure. As shown in Figs. 15 and 16, the larger area covered by restricted and unsuitable as a result excluded from further comparison because it is not economically or environmentally feasible. In this study the required area was 19 ha as the preferred size of a landfill site based on the volume and area calculated. There fore landfill site 1 and landfill site 4 were more suitable for municipal solid waste disposal by considering the distance from the center of the town.

4. Conclusions

Solid waste disposal system in Hossana town is open dumping. All types of solid wastes originating from industries, domestic, market and commercial center which contain leachable toxic compounds harmful to the environment and human health are dumped at the site without any treatment and separation. Besides, the existing dumping site is very close to the main road to Soro, Ajo River, and the residential areas causing serious environmental degradation and often ending up in the nearby rivers and open channels. This study which considers integrating AHP with GIS for spatial decision making is a valuable technique for dealing with large and conflicting factors in solid waste disposal site selection processes. The conjunctive use of the AHP and GIS was found effective in specifically in areas where solid waste management plans and decisions are made based on personal judgement and experience. Moreover, the integration was deemed efficient in finding out the optimized location in keeping the environment safe. All the factor maps prepared by the integrated AHP-GIS technique for the decision making process are not equally important. The factor maps were combined in order of importance to create an overall suitability map prepared based on tested and working guideline values. The suitability map prepared for the study area revealed that 70 ha, 668.3 ha, 3534.3 ha, and 4672.4 ha of the total land area fall under very highly suitable, highly suitable, moderately suitable and unsuitable showing less than 10 % of the area is suitable for the sanitary landfill in Hossana. The AHP-GIS integration also revealed that landfill sites selected are all found at the city peripheries which have an economic implication. Accordingly, site 1 and site 4 are selected as more suitable sites as compared to the sites 2 and site 3 due to their relatively larger land sizes. The proposed sites are easy to access and manage based on the criterion of the study area and other variables. They are located in North-East and South-West peripheries of the town with the selection area of bare lands, green spaces and urban agricultural land with less than 10 % slope.

CRediT authorship contribution statement

Tesfaye Doboch Wanore: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Validation, Writing – original draft. **Zelalem Abera Angello:** Formal analysis, Methodology, Visualization, Writing – review & editing. **Zemed Menberu Fetanu:** Methodology, Visualization, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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