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Research Article

Integrated AHP and GIS-Based Approach for Suitable Landfill Site Selection to Improve Solid Waste Management: A Case Study of Dessie Town, Ethiopia

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Abstract

This study aimed at selecting a suitable solid waste disposal site for Dessie town by utilizing an integrated geographic information system (GIS) and multi-criteria evaluation (MCE). To achieve the target of the study, the first step was determining the capacity of the required site by estimating solid waste generation rate and then overlay suitability analysis of different layers were done. To determine the rate of waste generation, amount of generated wastes collected from a total of 146 households and 59 non-households for seven consecutive date on April 2019. For selecting waste collection multi-stage sampling techniques were employed. For site suitability analysis, twelve relevant criteria were employed namely, proximity to river, road, residential area, water supply pipe, water well, reservoir, and prone areas, groundwater depth, slope, soil, geology, and land use/land cover. Analytic hierarchy process (AHP) was used to weight and standardized each criterion. The result shows that average daily waste generation rates were 0.45 kg / person / day. From suitability area analysis, 12.03% of Dessie town was suitable for landfill which satisfies the size of 1.49 km2 for the total municipal solid waste generated. Finally, the landfill site was selected from the candidate site which delineated from the suitable classes based on the size of the site, wind direction and to the center of the town using the comparison of weight of criteria in AHP evaluation. The result of this study will help as a preliminary input for further studies and the information supports for the concerned authorities to improve solid waste management of Dessie town.

Keywords: Analytic Hierarchy Process (AHP), landfill Site Selection, Geographic Information System (GIS), Dessie Town, Ethiopia.

1. Introduction

Globally, solid waste has become an increasing public and environmental problem for many cities and towns. It is enhanced by socio-economic factors such as fast population growth, urban expansion, industrialization, and migration from rural to urban areas [1]. Solid wastes eventually find their way into landfill, which are long-term storage facilities with no or little treatment, especially in developing countries including Ethiopia where solid waste management is one of an extreme problem [2].

Even if policies of waste reduction and reuse are applied, the existence of a sanitary landfill is necessary to a municipal solid waste management system [3]. Different disposal methods have been used for solid waste, such as landfill, incineration, and composting [4]. Among this, landfilling is one of the most common preferred methods for disposal [5]. This is because it is easy for operation, low cost, less technological involvement, and less environmental effects [6]. But, every piece of land is not suitable for landfills because uncontrolled landfilling pollutes the groundwater, surface water, soil and the ambient air quality [7]. However, if not suitably sited and managed it could cause severe problem to human health and the environment through disease transmission, breeding places for danger vectors, fire hazards, environmental pollution, aesthetic nuisance, and economic losses [8]. Landfill leachate and gases released from the landfill will result in groundwater, surface water and air

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pollution and have adverse effects on the local environment and is considered harmful to humans. This calls for siting landfill at considerable distance to waste generation center to avert potential environmental threats. So, proper disposal of the waste should be considered. This includes criteria to select the best site for landfills and proper landfill design. In addition, the landfill should have sufficient capacity to meet the current and projected waste to be deposited for at least 5 years [9].

According to stated that landfill site selection is complex because it depends on different factors and guidelines [10]. In terms of economics aspects, the price of the land depreciates as it getting nearer to the landfill sit [11].

The effects generated through the landfill are such as noise pollution, surrounding area are aesthetical unattractive, and also, air pollution [12]. Other than that, construction and operation of landfill requires high capital cost [13]. Nevertheless, landfill sites selection is a complex spatial problem linking multiple criteria and the study indicates that, the best solution exist for such complex problem is to use spatial models such as GIS and multi-criteria evaluation (MCE) techniques [14]. Because, the integration of GIS and MCE is a powerful tool to solve the problem of solid waste disposal site selection, GIS provides efficient manipulation and presentation of the data and MCE supplies consistent ranking of the potential landfill areas based on a variety of criteria [15].

Proper waste disposal is an imperative part of waste management system. But improper solid waste management could cause severe problem to human health and the environment through disease transmission, breeding places for dangerous vectors, fire hazards, environmental pollution, aesthetic nuisance, and economic losses. The problem of solid waste is mainly arising from unsuitable site selection and inadequate landfill site management [1]. In Ethiopia, most solid waste disposal sites are found on the borders of the urban areas around water bodies, faults, crop fields, settlements and on roads side [2]. Such inappropriate disposal of solid waste leads to serious environmental pollution and health-related problems, contamination of surface, groundwater and soil through direct waste contacts, greenhouse gas emission, ecosystems damage, injuries to people and property, decreases tourism and business activities [16]. The problems are similarly faced in Dessie town as 51.8% of residents practice 'open dumping' of their waste [17]. Presently, uncollected solid wastes are observed on the roadside, on abandoned land, in open sewers or river banks, drainage ditches and near homes that causes nuisance to the town dwellers and become the main source of public health problem. Solid waste is generally poorly managed and accumulated a lot of waste can be seen all over the town. The dump site named '' Membere Tsehay'' characterized by highly suspected erosion, steep slope, to the residents, poor road infrastructure, bounded by Borkena river in the southern direction. Households that live on the lower part of Borkena river are exposed to in respiratory and water borne diseases, when used for agricultural and washing. The bottom line here is that the site has various health and environmental issues. In this regard, the dump site has not been selected properly without considering scientific knowledge and engineering judgment. In fact, no the landfill site selection studies were conducted in the town. Therefore, this study aims to select the most appropriate solid waste disposal site for Dessie town by integrating the geographic information system (GIS) with the multi-criteria evaluation (MCE).

2. Methodology

2.1. Description of the Study Area

The study area is Dessie Town in south Wollo zone, on the eastern edge of the regional state of Amhara and in north central part of Ethiopia at a road distance of 400 km from Addis Ababa (Figure 1). Geographically, the town is located at the intersection of 11°8′N 39°38′E. which surrounded by a series of mountain ranges between the cliffs of Tossa and Azuwa. According to the Meteorological Agency of Ethiopia in Kombolcha station, the average annual rainfall for last ten years were recorded 1070 mm with the major rainfall occurring between July to September. The average monthly minimum and maximum temperature were 12.37 0c and 26.27 0C respectively. There are 16 kebeles that are geographically demarcated ,10 of which are urban and the remaining 6 kebeles and the total population were 232,203 in 2019 (Dessie Town Administration Office, 2018).

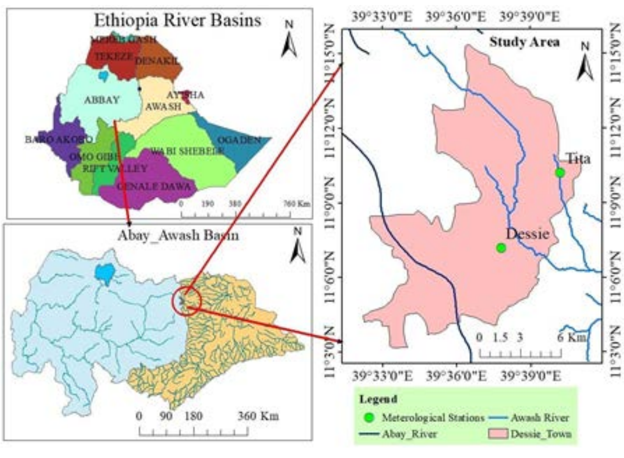

Figure 1: Map of the study area

2.2. Methods of Data Collection

All the necessary data required for the study were obtained from both primary and secondary sources.

2.3. Primary Data

Weight of solid waste was collected in primarily through field measurement, walk survey and observation for each class of waste. The class of wastes are residential commercial, institutional of street sweeping. The data were collected and weighted at the point of generation.

2.4. Secondary Data

Secondary data were collected from government and non-government publications, annual and inventory reports, previous studies, books, Sanitation Beautification, and Park Development Department (SBPDD), municipality, finance, and health office of Dessie town (Table 1).

Table 1: Secondary data and sources

S. No	Type of Data	Sources of data	Purposes
1	Soil map	Ministry of Agriculture	Spatial soil data and suitability
2	DEM	https://earthexplorer.usgs.gov/	For slope map in GIS
3	Geological map	Geological Survey of Ethiopia	For suitability analysis
4	Structure plan	Urban development office	For digitizing for Residential, Road, prone areas, LULC and River
5	Demographic characteristic's	Urban administration	Solid waste collection
6	Water supply related data	Dessie Town Water supply and Sewerage office	For suitability

2.5. Sampling Size and Sampling Techniques

In this study, multi-stage sampling method was used based on geographical location, population density, and availability of different infrastructures. First, 16 kebeles of Dessie were stratified in to three strata based on their geographical locations, i.e., inner (kebeles close to the center of the city), middle (kebeles located in middle distance from the city center), and periphery (kebeles located far from center of the city). In the second stage, a total of three kebeles (one from each stratum) were selected using simple random sampling. This is mainly because it is believed that those kebeles located in each stratum have homogenous characteristics with respect to proximity to the center of the town and population density. Then, the sample size of household was determined by using scientific statistical method [18, 19].

$$n = \frac{NZ^2PQ}{d^2(N-1)+Z^2PQ} \quad (1)$$

Where: n=sample size of housing unit, N = total number of households, 54,000 P= housing unit variable (Residential houses which is 90% of N); Q =1-P (non-residential houses which are 10% of N); Z = standard normal deviation at the required confidence level that corresponds to 95% confidence interval equal to 1.96 and d=level of statistical significance (allowable error) is 0.05.

$$n = \frac{54{,}000*1.96^2 0.9*0.1}{0.05^2(54{,}000-1)+1.96^2*0.9*0.1} = 141$$

In the present study, instead of 141, 146 households were considered to take care and non-response rate. This was to have an equal distribution of sample size over 3 kebeles by using proportional random sampling in Table 2.

Table 2: Sample size allocation based on projection for residential

Stratum	Kebeles	Sample kebeles	Total number of households in each sample kebele	Proportional percentage	Number of sample households
Inner	02,04,05, 06,07	07	2702	24	35
Medium	01,03,08, 09,10	03	6583	58	84
Periphery	11,12,13, 14,15,16	15	1950	18	27
Total	16	3	11235	100	146
Source: - Dessie Municipal Office, (2018)					

For non-residential solid waste generating activity, the sample size was determined by using the sampling technique formula adopted from with a possible standard deviation of similar study 0.1632 (Sharma & Mcbean), the Confidence level 95 % and 5 % allowable error.

$$n = \frac{\sigma^2 Z^2}{SE^2} \quad (2)$$

Where, Z= value to 95% confidence interval and equal to 1.96; σ = standard deviation; SE = standard error.

Therefore, 59 units were the minimum reliable total sample size of non-residential units, while thirteen units were added by considering non-volunteer rate.

The total sample size was 59 units, and these amounts were distributed in each waste stream. Those waste are categorized under commercial waste, institutional, street sweeping and others.

2.6. Waste Streams and Sample Allocation

There are several possible methods that can be used for solid waste investigation. In this study, quantification or measuring the amount of waste and characterization of waste were used through visualization and through hand sorting. Quantification was done at the point of generation. From each of the selected sampling sites, a total of 205 solid waste samples were collected directly at their point of generation and characterized visually and sorted by hand into their respective categories as biodegradable and non-biodegradable. The sorted wastes were quantified by determining the amounts of solid wastes disposed in given period at their source. Investigation was carried out every morning at 2:00 AM throughout the study (April 2019). Finally, the sample size was allocated by using simple random sampling.

After assigned all samples 30 samples were taken for commercial waste in the city as shown Table 3. Samples were allocated with the proportion of commerce types. Zoning of commerce were selected by waking survey. Also, 15 samples were taken for institutional waste stream. For street sweeping solid waste taken from one sample for each 5 km interval in total of 70 km asphalt coverage of the town. So, 14 sample were taken from street sweeping collection points.

Table 3: Waste Streams and Sample Allocation

No	Waste streams	No
1	Residential	146
2	Commercial	30
3	Institutional	15
4	Street sweeping	14

2.7. Solid Waste Composition

After all, waste collected from each source were weighted before sorting to determine the total waste collected from each individual establishment in April ,2019 for consecutive seven days' survey and total waste collected per day, the composite waste samples from each type of plastic bags were distributed and have been sorted in to different types of waste components. After weighing each sample accurately, samples of each category were prepared and segregated manually, and then each segregated item was weighed separately and recorded. For the analysis of the percentage share by weight of the waste composition six significant waste fractions were considered in the study as presented in Table 4. By taking the average weight of each fraction, their percentage share in the waste stream was determined.

Table 4: Waste Composition Fractions Considered in the Study

Waste fraction	Waste composition
Food residue	Food remnants, discarded vegetables, fruit peelings
Wood waste	Discarded wood products, whole trees, stumps, ash and charcoal
Paper	Paper scraps, book, printed materials, cardboards, newspapers, packaging papers, discarded papers
Plastic	Plastic packages, polyethylene bags, rubber, polyethylene bottles
Textile	Discarded clothes, rags, organic and synthetic based closes
Rubber	Tires, inner tubes, waste oil waste plastics and rubber
Source: Tchobanoglous & Kreith, 2002	

The percentage weight of each of the physical waste fractions was calculated by the following formula as used by [20]:

$$\%\, Weight \text{ of waste fraction} = \frac{Weight \text{ of separated waste}}{the\ total\ weight\ of\ mixed\ sample} \times 100$$

Then, recyclable solid waste that has the possibility of being valuable material for the community was considered.

2.8. Estimation of Solid Waste Generation Rate

The per capita waste generation rate in the study was obtained by dividing the total weight of the waste generated by the studied population multiplied by the number of waste generation days as in as follows [20]:

$$G_{pc} = \frac{W_T}{P \times n}$$

Where, G_{pc} = per capita waste generation rate; W_T= total weight of waste collected in 7 days; p= studied population, n = number of collection days.

The population and the expected amount the solid waste generation rate was estimated based on geometric increasing method [21]:

$$P_t = P_o\,(1+K)^n$$

Where, P_t = expected future population at period of year t; P_o = present population for year 2019; n = number of years; K = annual growth rate.

The quantity of waste produced from residential (Qs) for each year calculated based on Equation 3.6 [22].

$$Q_s = P_t \times GRSW \times (\frac{365}{1000})$$

Where, P_t = Expected future population at each year; GRSW=Projected generation rate of solid waste for each year (Kg/c/d).

According to, commercial and institutional solid waste is increased by 2 % per year [23]. Total municipal solid waste (Q total) generated was calculated as the sum of residential and non-residential solid waste as: -

$$Q_{Total} = Q_s + Q_c$$

Where, Q_s = quantity of solid waste produced from residential each year (ton); Q_C =quantity of solid waste generated from non-residential each year (ton).

The computed waste quantity was then converted to equivalent landfill volume by dividing waste quantities to the compacted specific weight. The compacted density of the solid waste was determined by weight-volume analysis. The compacted density of the MSW was adopted as 500 kg/m^3. Hence, the result obtained in this study laid in the density range of readily achieved with proper landfill compaction machine operation 400 to 600 kg/m^3 [23]. Waste in the landfill must be covered daily in order to minimize health hazards and maintaining safety environment. The volume of annual cover for landfill is 30% of total waste volume [24].

$$\text{Volume} = \frac{\text{total quantity of solid waste}}{\text{compacted density}}$$

"Cover volume"="30% of total volume"
Total volume=volume +cover volume

$$V_c = V_{ct} + V_{(ct-1)}$$

Where, V_c = cumulative volume for specific year (m^3); $V_{(ct)}$ = total volume for specific year (m^3); $V_{(ct-1)}$ =cumulative volume for the last year before specific year (m3).

Then, the area of the landfill is the ratio of cumulative volume to the depth of landfill. The landfill depth of 3 m was used (Britsh Columbia Ministry of Environment, 2017). According to Britsh Columbia MoE and Wu an additional 20% of the area was added for infrastructure [25].

2.9. Data Analysis

Microsoft Excel for characterization of solid waste and ArcGIS 10.8.1 for suitability of landfill site were used to achieve the objectives of this study. GIS spatial operation tools were used digitizing, buffering, overlay, and spatial analysis. Digitizing means 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. Buffering is used to generate areas of a given distance around the specified criteria used for landfill site selection. An overlay operation was performed to identify areas that fulfill all the site selection criteria and to show areas that do not meet these criteria.

2.10. Evaluation and Reclassification of Criteria

Landfill site selection studies depend on the natural and legal condition of an area. In this regard the criteria and principles considered in this study were technical criteria. These criteria contained their own components and were selected according to the guide directions and legislations of EPA and municipality. Based on FAO classification, all the factors were internally classified in to five classes (most suitable, suitable, moderately suitable, poorly suitable, and unsuitable) with values ranging from 5 to 1, where 5 denotes the most suitable and 1 denotes the unsuitable for all factors and constraints considered.

2.11. Slope

The slope map was created from the investigation area of the DEM map with a resolution of 30*30 m in a GIS environment. Considering the suggestions in the literature, the slope map is divided into five groups. Areas with a percentage slope > 20% & 0-4% was unsuitable, 4-8% less Suitable, 16-20% moderately suitable, 12-16% suitable and 8-12% most suitable [26].

2.12. Geology

The geological map of the study area was obtained from the Ethiopian geological survey. The map was then georeferenced and digitized in the GIS environment. Geological units were used to assess the permeability and stability of the rocks. According to, the permeability of the formation in the region depends not only on the primary porosity, but also on the secondary porosity resulting from weathering and fracture [27]. The stronger the weathering and fracture, the more permeable and unstable the rocks become.

2.13. Rivers

There are two watersheds in the study area, Blue Nile, and Awash watershed. Under these watersheds lie the Borkena River from north to south and the Gerado River to the southwest of the city. A small river called Gimwuha also flows into the Borkena River. In this study, 200 m buffer distance was used as a minimum distance from which landfill can be sited. Accordingly, Multiple Ring Buffer from Analysis Tools was used to prepare multiple polygons around each river within the following distances: 0-200,200-500, 500-1000,1000-1500 and > 1500m. To minimize the effect of landfill leachate on river pollution, 0-200 m buffer area was excluded from siting process. The rest of the areas were analyzed based on the distance from the rivers [28].

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2.14. Water Well Points

In this study area, fifteen water well points that are currently functional and then multiple ring buffer tools were used to prepare buffer zones around each well. Proximity of a landfill to a groundwater well is an important environmental criterion in the landfill site selection so that wells may be protected from the runoff and leaching of the landfill. Hence, solid waste disposal should be placed away from water wells. Otherwise, it can have irretrievable human and environmental effects. As a result, proximity from groundwater well was considered as an important criterion for this research [2]. For this work, 500m buffer distance was used. Moreover, additional buffering was performed around the wells in order to identify the best site for landfill. Buffer distance of 0-500m, 500- 800 m, 800-1200, 1200- 2000 m and >2000 m were prepared around each and every well points [29].

2.15. Soil

The most the amount of soil permeability, the most probable the flow of leachate to pollute the environment. In soils with low permeability, the producing leachate may stay within landfill area [5]. Hence, in study area there were six class of soils, clay, clay loam, clay to clay loam, clay to silty clay loam, sandy clay and silty clay.

2.16. Residential Area

According to, minimum distances for the study area were determined as 300 m for residential areas. These distances were used to create buffer zones around settlement areas and excluded from the study area within 300 m and more than 1500m [30]. Generally, areas were classified as 0-300 m, 300-500m, 500-1000 m, 1000-1500 m and >1500 m according to their suitability by ranking with the help of literature review.

2.17. Land Use/Land Cover

Land use/land cover map obtained from the structure plan of the study area and eight different land use types were included in this study. The identified uses in the study area were included agriculture, forest, mixed use, open space, unclassified, vegetation, and water body and built up.

2. 18. Roads

Road networks were obtained from the structure plan of the study area. In the present study by considering the two extremes, the suitability of road network classified as 0-200 200-500,500-1000 ,1000-1500, 1500-2000 and >2000, the suitability is low vey near to the road and very far from it, because of traffic congestion and more transportation expense respectively [31].

2.20. Reservoir

There are 25 reservoirs in study area and the map were buffering in multiple ring tool in GIS environment. The study area was classified in to 0-400 m, 400-800 m, 800-1200 m, 1200-1600 m and > 1600 m [23].

2.21. Water Supply Distribution Pipe

Water supply distribution pipe network was obtained from Dessie town water supply and sewerage office in Water CAD format. Then pipeline data was classified by buffering distance in to 0-300 m, 300-800m, 800-1200 m, 1200-2000 and > 2000 m [32]. One way to degrade the water quality in the distribution system is by leaching waste into the pipe through leaks and the growth of bacteria on surfaces such as biofilms. Municipal solid waste landfill leachate is allowed to contaminate water that is or could be used for domestic supply. Hazardous contaminants are present in municipal landfill leachates that need to be considered in evaluating the public health and water quality impacts of MSW landfills [33].

2.22. Prone Areas

Prone areas were obtained from the structure plan of the city through merging a layers' that was considered a protected area. The study considers as criteria a may pose a problem for landfill sites. These are: Flooded areas, intervention, and landslide areas. When choosing landfill sites for municipal waste disposal, the risk of natural disasters was used [34]. A buffer of 1000 m is formed, and a score of 0 is given as the distance of less than 1000 m from landfill will make protected areas vulnerable. According to the expert opinion, a landfill should not be in potentially unstable zones.

2.23. Groundwater Depth

For the preparation of groundwater Table map, fifteen water well data were obtained from the Dessie town water supply and sewerage office and a kriging interpolation was carried out. Moreover, stated that areas with greater than 50m ground water depth are most suitable for landfill site but unsuitable in areas with less than 10 m groundwater depth, so the suitability increases the value given from 1 to 5 [35]. Sites were classified in to five as 0-10 m, 10-20, 20-40 m, 40-50 m, and >50 m. Accordingly, the suitability increases with increasing depths.

2.24. Assigning Criteria Weight

In the study, the multi-criteria analysis was used as a decision rule to analyze the data for the landfill site selection with the help of a pair-wise comparison matrix. It helps to prioritize between the elements with each layer of the hierarchy. As cited by in Saaty, in AHP, the 9-point scale which ranges from 1(indifference or equal importance) to 9 (extreme preference or absolute importance) were used in the decision making process for landfill site selection in Dessie town in Table 5 [36]. Hence, twenties five experts were participated in decision making process for pair wisely comparative. Those experts were including; academicians, EPA, Ethiopian Environment and Forest Research Institute (EEFRI), and environmentalist.

Table 5: Number of Experts

Expert from	No
Environmental protection Authority	5
EEFRI	7
Academics	6
Environmentalist	7
Total	25

The experts gave their opinion about the importance of each factor relative to another factor in the landfill siting process based on Table 6.

Table 6: Scale of the Importance of Pairwise Comparisons (Saaty)

Intensity of importance	Definition
1	Equal importance
2	Equal to moderate importance
3	Moderate importance
4	Moderate to strong importance
5	Strong importance
6	Strong to very strong importance
7	Very strong importance
8	Very to extremely strong importance
9	Extreme importance

Then, the relative importance of the criterion's weights was calculated by the geometric mean of each row of the pairwise comparison matrices as cited by on Saaty [37].

Consistency of the judgment matrix was tested, and then the weighted sum vector was calculated as paired comparisons matrixes multiply by relative weight. The consistency vector was gained by dividing the weighted sum vector components by the relative priority vector. The eigenvector (λmax) is the average value of the consistency vector. The consistency index (CI) was calculated by the formula [38].

$$CI = \frac{\lambda_{max}}{n-1}$$

Where, n = size of the matrix. The consistency ratio (CR) was obtained according to in Equation 3.11. CR must have value < 0.1; indicate consistency (Saaty) [39].

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

Where, RI is a random consistency index depending on the size of the matrix in Table 7. A reasonable level of consistency in the pair wise comparisons is assumed if C.R. < 0.10, while C.R. ≥ 0.10 indicates inconsistent judgments.

Table 7: Random Consistency Index (R.I.) for N=1, 2 ... 8 (Adapted from Saaty, 2008).

N	1	2	3	4	5	6	7	8
R. I	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41

Materials used for data collection

Materials used during the survey include: -Sacks for collecting waste, digital scales for measuring a weight, plastic film for sorting waste, safety / personal protective equipment, format sheet for recording, camera for recording the events of the survey. The overall process of this study was shown in figure 2.

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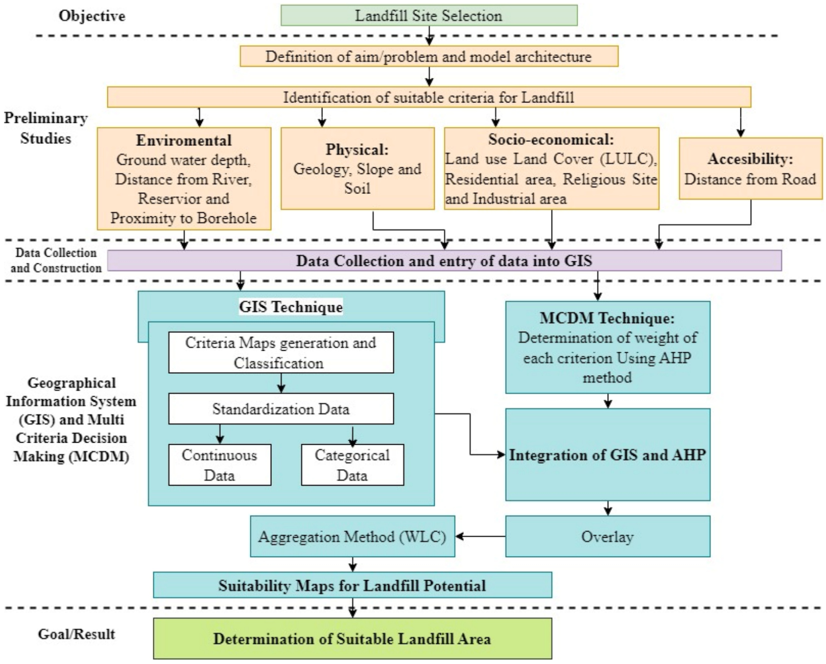

Figure 2: The General Steps of Selection of Landfill Site Suitability in Dessie Town.

3. Result and Discussion

3.1. Solid Waste Generation Rate

The daily solid waste generation rate for Dessie town for large, middle, and low population density were 0.51 kg/c/day, 0.46 kg/c/d and 0.37 kg/c/d respectively. This indicates that the waste generation rate of high population density was higher than lower population density. Solid waste generation rate in this study has direct relationship with the population size similar to finding of [40, 41]. This maybe as result of high population growth and urbanization have expected to use more consumptions of materials than low population number in particular zone.

The average daily waste generation rate of the domestic solid waste in 2019 was obtained as 0.45 kg/capita/day. This generation rate is completely the same values with other studies carried out at 0.45 kg/cap/day at Dessie by and 0.44 kg/cap/day at Addis Ababa by [42].

3.3. Physical Composition of Municipal Solid Waste Composition

In this study, physical composition of solid waste was determined from the sources of municipal solid waste i.e., residential, commercial institutional and street sweeping. The average percentage waste compositions entire waste streams are generated in the study area (Figure 3).

As shown Figure 3, out of the total waste collected, food wastes constitute 37.32% of the average MSW by wet weight. This indicated that the major waste faction is high organic waste and moisture content waste. Similarly stated that the larger portion of solid waste of Bishoftoo Town is food waste (38.9%) [43]. Next to food wastes, paper, (18.32%) and plastic (11.30%) by weight, and the least solid waste are rubber (3.89%). which is high compared to some towns of the country. Out of the total MSW generated, 15 % of total MSW could not be recycled.

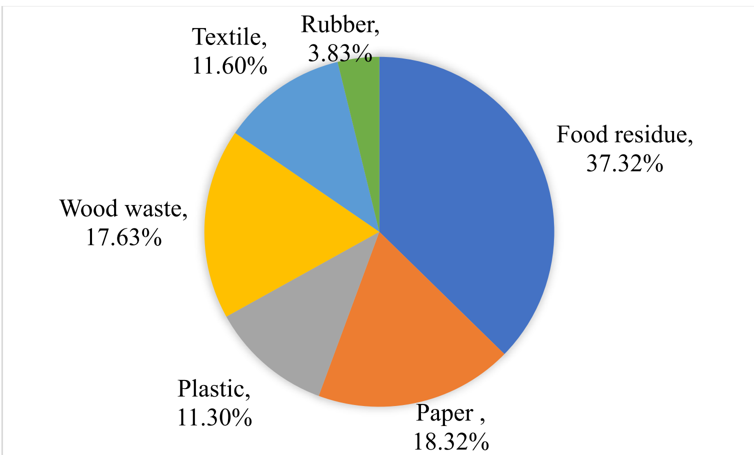

Figure 4: Average Percentage of Waste Composition

3.4. Prediction of Municipal Solid Waste and Landfill Demand Assessment

Demand of land for Municipal Solid Waste (MSW) disposal in landfills depend on various factors. Typical factors include future population, trends of waste generation, waste management objectives, waste diversions, change of consumer's habit, urban growth, and so on. Accurate estimates of present and future waste generation and composition of waste are essential for integrated waste management. Waste quantity can be used to determine type, size, and design of waste disposal facilities [44]. In table 8, shows that, the total solid wastes of Dessie town generated for residential (67.71%), commercial (24.08%), institutional (3.52%), and street swiping (4.69%).

Table 8: Total Municipal Solid Waste (MSW) Quantity

No	Waste streams	Total weight	Percentage
1	Residential	4897.81	67.71
2	Commercial	1741.98	24.08
3	Institutional	254.69	3.52
4	Street	339.10	4.69
	Total	7233.57	100.00

The population of Dessie will be about 538956 in 2039 using the equation (3.5) with an estimated population growth rate of 4.3% was used to estimate the number of Dessie's population in the next 20 years, while equation (3.4) was used to estimate the amount of solid waste generated by the municipality by adopting the average daily generation rate for the individual as 0.45 kg /capita/day. The result reveals that in Table 4.6 drawn from the two equations cited above, note that the amount of solid waste generated in the city of Dessie by 2039 will be 98560.05 ton, due to the growth rate of Dessie's population and consumption of goods and products, as the increase in consumption is accompanied by an increase in the generation of solid waste. Population, waste generation and corresponding waste volume are shown in Table 9.

Year	Projected population	Yearly waste generation (M tons)	Total volume (m3)	Cumulative volume (m3)
2019	232203	44893.54146	116723.208	116723.2078
2020	242187	46668.61717	121338.405	238061.6124
2021	252601	48516.91421	126143.977	364205.5894
2022	263463	50441.51895	131147.949	495353.5387
2023	274792	52445.64924	136358.688	631712.2267
2024	286608	54532.66003	141784.916	773497.1428
2025	298932	56706.04925	147435.728	920932.8708
2026	311786	58969.4639	153320.606	1074253.477
2027	325193	61326.70647	159449.437	1233702.914
2028	339177	63781.74158	165832.528	1399535.442
2029	353761	66338.70293	172480.628	1572016.069
2030	368973	69001.90056	179404.941	1751421.011
2031	384839	71775.82835	186617.154	1938038.165
2032	401387	74665.17195	194129.447	2132167.612
2033	418647	77674.81699	201954.524	2334122.136
2034	436648	80809.85762	210105.63	2544227.766
2035	455424	84075.60547	218596.574	2762824.34
2036	475008	87477.59895	227441.757	2990266.097
2037	495433	91021.61301	236656.194	3226922.291
2038	516737	94713.66921	246255.54	3473177.831
2039	538956	98560.04637	256256.121	3729433.952

Table 9: Population, Waste Generation and Waste Volume of Dessie Town (2019-2039)

To assess the landfill area requirement waste quantities is to be converted into compact volume. According to British Columbia Ministry of Environment (2017), a well-run landfill can achieve a compacted density up to 600 kg/m3. However, wastes are a mixture of materials with different properties and characteristics. Some materials compact much more readily than others. In this study, for calculation of waste volume a compact waste density 500 kg/m3 is adopted. Then, computed waste quantities are converted to equivalent landfill volume dividing waste quantities by the compacted specific weight (500 kg/m3) of waste in landfills.

From the total MSW of Dessie town, paper (13.86%), plastic (11.30%) and food waste (30.47%). However, commercial waste has varied percentage components and depends on its sources. Different studies show that about 10% of total generated waste is picked and recycled by scavenger [44]. But, in the study waste reduction scenarios as shown in Figure 5 is calculated for the possibility of recycling were 15% and corresponding waste volumes for different period.

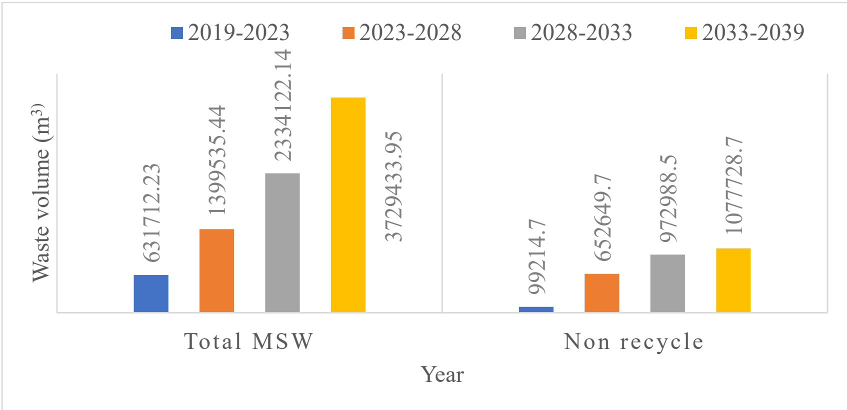

Figure 5: Waste Volume (m3) for Different Waste Management Scenario

3.5. Landfill Demand Assessment

The required landfill area over the next twenty years is shown in Table 10. Hence, in this study 1.49 km2 of landfill area demand is required if all wastes are disposed to landfill whereas 1.27 km2 of landfill area is needed for 15% of the waste are expected to recycle.

Table 10: Landfill Area Demand

Components	Total MSW	Non recycle
Accumulative volume (m3)	3,729,433.952	1077728.7
Area (m2) for 3m height	1,243,144.651	359242.9
20% of area allowance (m2)	24,8628.93	71848.58
Area required (m2)	1,491,773.25	431091.48

3.6. Landfill Site Selection Criteria Suitability

Slope: In this study, areas with high slopes were taken as not suitable for landfill site allocation. This is because when the area becomes steep it may be vulnerable for erosion and will result in contamination of surface water through flooding. Besides, the construction cost of excavation increases in the higher slope area. The suitability of slope was determined based on the criteria set by [30, 32].

In this study, the area dominated by the slope (0-4% and >20) which is 33.68% of the total study area was unsuitable for landfill establishment due to the topography requires high construction costs of excavation. However, 17.93% of the study area is most suitable by the slope 8-12% because of its easy for preventing leachate flowing and runoff. The remaining topography of the study area covers by less suitable (4-8%), suitable (12-16) and moderate (16-20) which comprises 29.59%,12.32% and 6.48% respectively as shown Figure 6a.

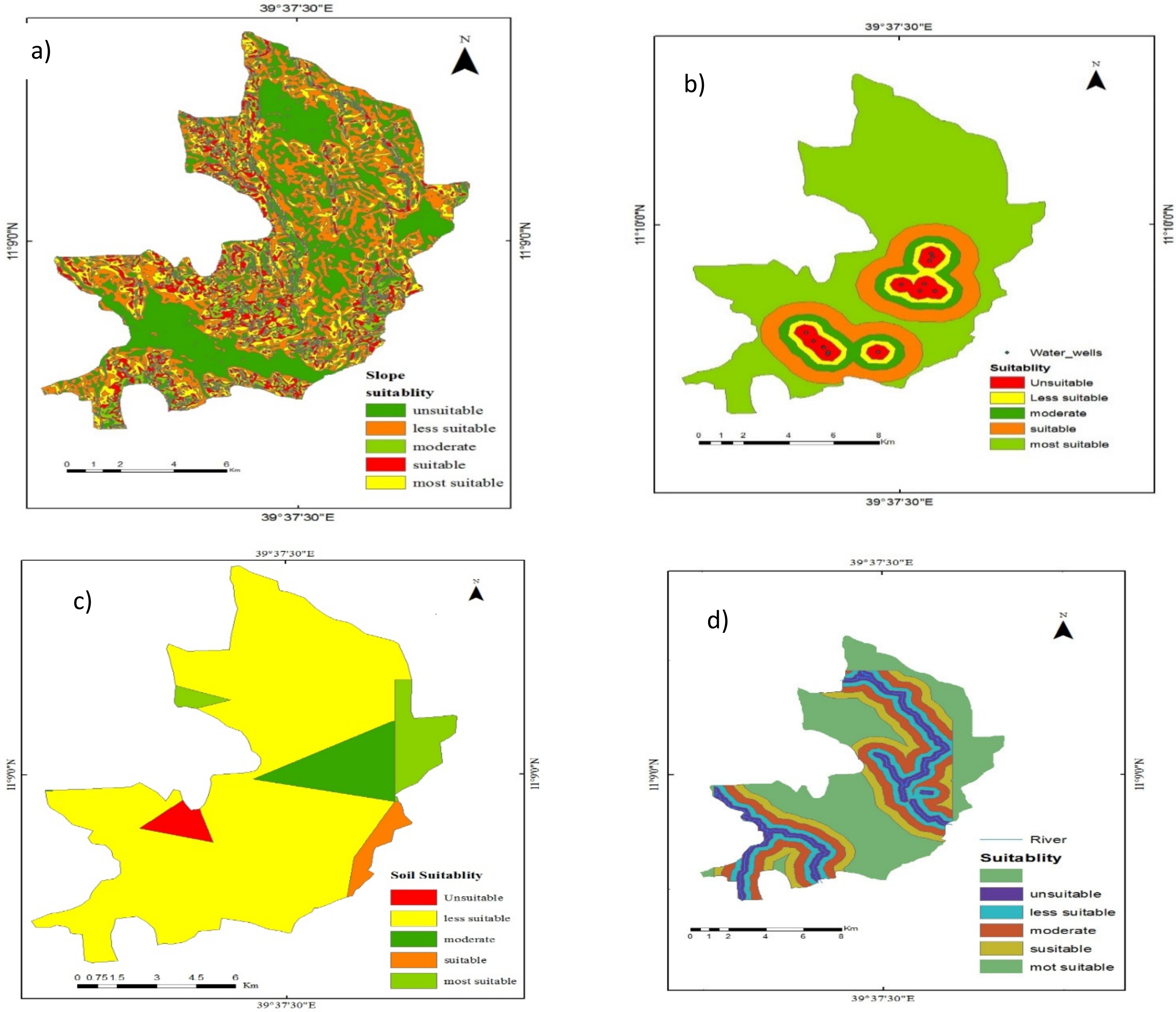

Figure 6: Criteria Suitability of a) Slope Suitability, b) Water Well Proximity Suitability Map, c) Soil Suitability Map and d) River Suitability Map

Geology Suitability: Tertiary extrusive and intrusive geological units are dominant in the study area and due to their primary porosity, are very permeable because of less degree of weathering and fracture and therefore unsuitable for landfills. Therefore, such formations are unsuitable for landfilling of solid waste because of the high likelihood of groundwater contamination.

Water Well points Suitability: Landfill very far from water well will have minimum effect and the vice versa. Generally, the more closely the landfill, the more probable for ground water to be contaminated. The suitability with respect to the proximity to groundwater well is as shown Figure 6b.

Figure 6b shows that 2.94% of the total study area is most suitable from ground water proximity point of view because the areas are far from groundwater well and 94.42% is not suitable as they are in the vicinity of water wells. Moreover, 0.61%, 0.79% and 1.24% are less, moderately, and suitable, respectively.

Soil suitability: The suitability of area with respect to soil type is presented in Figure 6c. As shown in the figure 6c, soil types of the study area are strongly characterized by the loam soil texture, which is covered by 82.6% of the total area and was less suitable due to the permeability, which is in the north and mostly in the southwest of the city. Also, 5.87% of the study area covers by clay which is most suitable due to impermeability for landfill site selection, which is located at northwest of the city. The remaining 2.18%,7.40% and 1.95% of the study area are suitable, moderately, and suitable for landfill site respectively.

River Suitability: The river suitability for landfill sitting is presented in Figure 6d. The result shows that 11.54% of the study area was unsuitable which found at the north and

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central part of study area and within 200 m distance from river Borkena and Gerado. This is due to the possibility of contaminants from a landfill leaching to the rivers, which can cause pollution. The most suitable area is in most southern, north, and central parts of the study area, which covers about 37.57% %, these locations most ideal due to the minimum effect on surface water. The remaining, 15.5, 20.54, and 14.8% of the total areas were suitable, moderately suitable, and less suitable, respectively.

Land Use Land Cover: The suitability of LULC for landfill site selection is displayed in shown Figure 7a. From the result of this study, 39.18% of the total area was unsuitable due to the area covers by the open space, vegetation, and water body. While, 17.64% of the total area was most suitable because of its area covers by built up. The remaining of the study area were covers 0.04% (less suitable),14.07% (moderately) and 9.08% (suitable) by mixed use, forest, and agriculture.

Residential area suitability: The suitability of distance to the residential area is presented in Figure 7b. The results given in Table 4.9, 86.73% of the study area covers most suitable for siting landfill due to no negative impact on the environment and public health. These areas are found in most of southeast and north of the study area in Figure 7b. While 4.25% was unsuitable, because of possible adverse health effects for populations living nearby, these are in the most central part of the study area. Moreover, 2.55, 4.09, and 2.38% were suitable, moderately suitable, and less suitable, respectively.

Road suitability: The road suitability map for landfill siting is illustrated in Figure 7c. From the result of suitability for road indicates that 58.64% of the investigation area was unsuitable; these are in the southeastern and northwestern parts of the study area. This is due to the possibility of a negative aesthetic effect. The most suitable area was observed in the central parts of the study area, which encompassed an area of approximately 2.27%, as shown in Figure 7c. This is because the location is a suitable distance from the road network in order to reduce transportation costs and protect human health. In addition, 12.25%, 26.36% and 0.48% of the areas were rated as suitable, moderate, and less suitable, respectively.

Reservoir suitability: Reservoir suitability map is presented in Figure 7d. The result of the reservoir suitability indicates that the largest part of the investigation area (83.07%), was best suited due to a location far away from a reservoir and has no negative effects. The most suitable area was found in most of the central part of the study area in Figure 7d. While 1.39% was unsuitable because of this area near the reservoir, it can have a negative impact on humans, mostly found in the western part of the city. The remaining 6.07, 5.67 and 3.8% were suitable, moderately suitable, and less suitable for landfill.

Groundwater depth suitability: The suitability map with respect to the GWT depth is shown in Figure 7e. The groundwater depth suitability results indicates that 27.15 % of the study area was most suitable. In fact, that, deep GWT depth is preferable for landfill. These areas are located at south and northeast parts of the study area (Figure 7e). Due the fact that deep GWT depth is preferable for landfill. While, none of the study area covers unsuitable due to the area not appropriate shallow water Table that has less than 10 m depth. The remaining, 31.13, 41.08, and 0.64% of the study area were suitable, moderately suitable, and less Suitable, respectively.

Water supply distribution pipe: The suitability respected to water supply pipe distribution is illustrated in Figure 7f. The water supply pipe distribution suitability results shown in Table 4.13, indicates that 36.6% of the study area was most suitable. The water supply distant from the landfill is suitable for drinking to ensure public health and to minimize leaching of waste into the pipeline. These areas are located at southwest and northeast parts of the study area (Figure 7f). While 23.11% of the study areas were unsuitable because pipelines near the landfill have a negative impact on water quality. The remaining, 7.34, 7.98, and 24.96% of the study area were suitable, moderately suitable, and less suitable, respectively.

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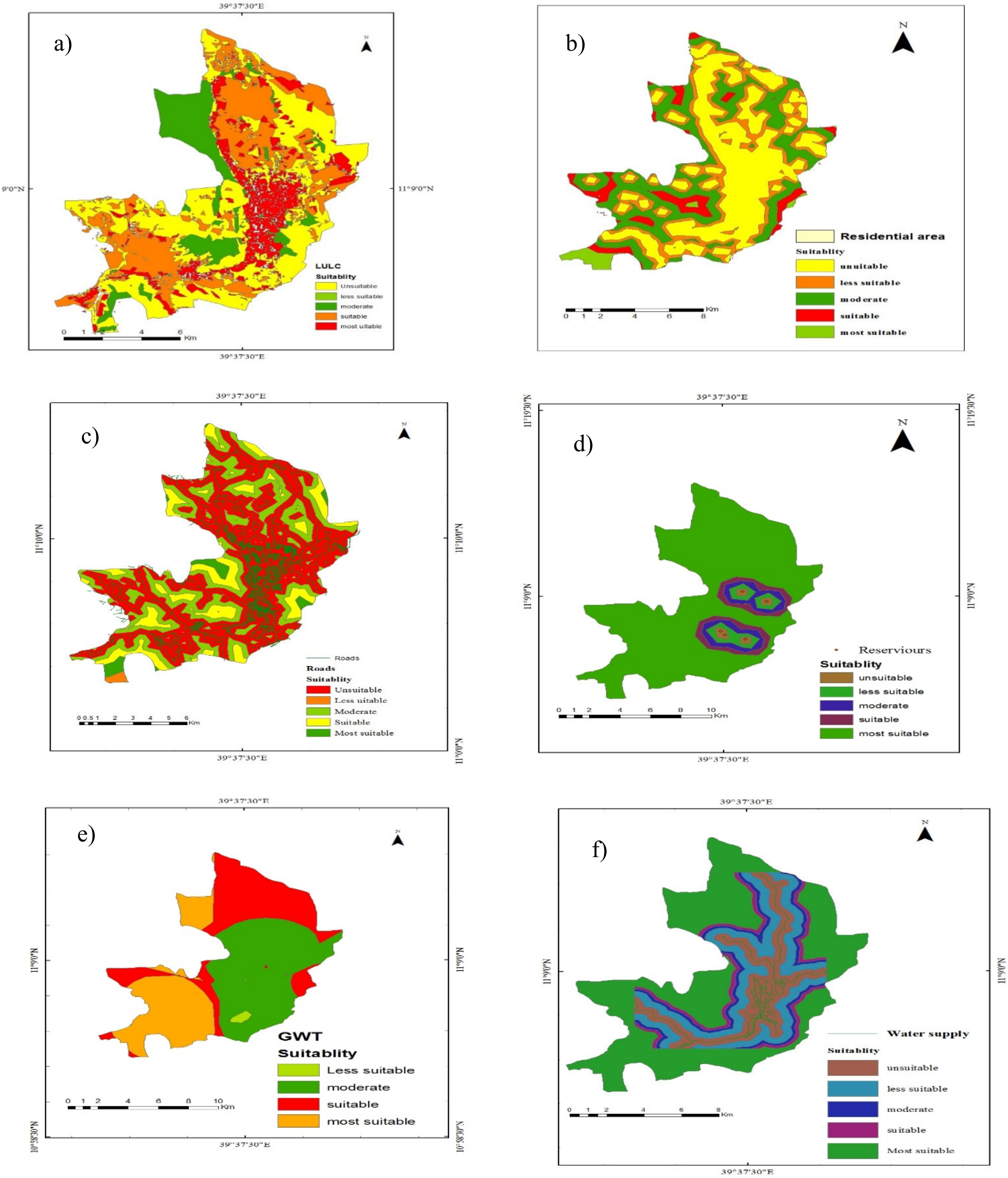

Figure 7: Suitability Criteria of a) LULC Suitability Map, b) Residential Area Suitability, c) Road Suitability Map, d) Resrvoir Suitablity Map, e) Groundwater Depth Suitability and f) Water Supply Pipe Distribution Suitability Map

Prone Areas: The prone area suitability is presented in Figure 8. As shown Figure 8, the study area of probable area is strongly characterized by landslide area, which is covered by 94.49% of the total area and was less suitable due to natural disaster, which is located at the most of northwest and south part of the city. While ,0.68% of the study area covers by unclassified area which is suitable due to not subjected for sensitive area on landfill site selection, which is located at central part of the city. The remaining 1.12% and 3.71% of the study area are moderately and less suitable for landfill site respectively.

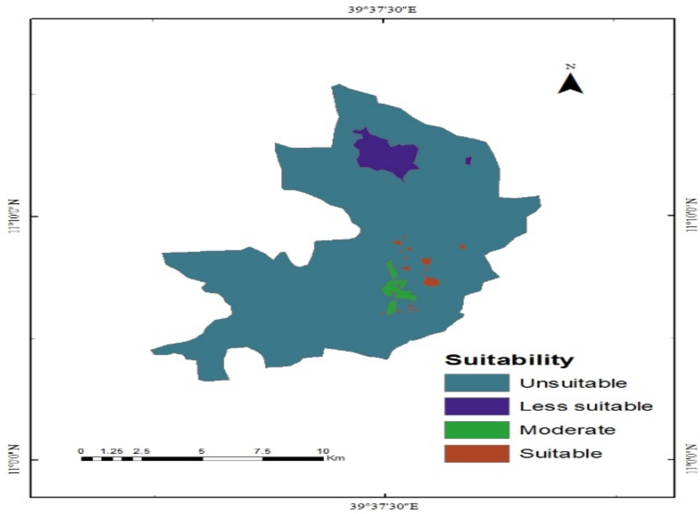

Figure 8: Prone Area Suitability

4. Result of Weight Criteria

The relative importance of criterions was filled by twenty-five experts' opinion and the results were obtained by the geometric mean of each row of the pairwise comparison matrices. Based on AHP calculation, the weight module develops the pairwise comparison technique to help derive the weight and its consistency ratio for solid waste disposal site selection of the study area. According to, if the consistency ratio is less than or equal to 0.1, it shows an acceptable reciprocal matrix [45]. The consistency ratio of this study indicated that 0.088 was acceptable. The importance of environmental and socio-economic factors in determining landfills is not the same. Therefore, factors values and weights are summarized below in Table 11.

Table 11: Pairwise Comparison Matrix of Criteria

Criteria	ST	S	G	RO	R	GWT	RA	LULC	WW	Rv	PA	WSP
ST	1	1	½	1	½	½	1/3	1/5	1/4	1/2	2	1/2
S	1	1	1	3	½	1/3	1/4	1/2	1/4	2	1	1/2
G	2	1	1	1	1	½	1/4	1	1	1	1/2	2
RO	1	1/3	1	1	1	1/3	5	1	1/2	1/2	1/3	1/2
R	2	2	1	1	1	½	1/3	1	1/2	2	4	2
GWT	2	3	2	3	2	1	1/2	3	1	2	3	2
RA	3	4	4	5	3	2	1	1	2	3	2	2
LULC	5	2	1	1	1	1/3	1	1	1	1	1/3	1/2
WW	4	4	1	2	2	1	1/2	1	1	2	1/2	2
RV	2	2	1	2	½	½	1/3	1	1/2	1	1/2	1/2
PA	½	1	2	3	¼	1/3	1/2	3	2	2	1	1
WSP	2	2	½	2	½	½	1/2	2	1/2	1	1	1

(Note: ST= Soil types, S=Slope, G= Geology, RO = Road, R=River, GWT =Ground water Table, RA=Residential, LULC= Land use Land cover, WW= Water wells, Rv=Reservoir, PA=Prone areas, WSP= Water supply pipeline). Shaded one means the weights are equal. The weights of the criteria obtained from the computation of the pairwise comparison matrix is presented in Table 11.

Analysis of the weight result of AHP in Table 12 shows that residential area, GWT depth and proximity to water wells have a greater influence than the other factors as they are very important in protecting groundwater pollution from landfill leachate and maintaining human health. Weldeyohanis stated that proximity to residential area is a most important factor. Dolui & Sarkar also indicated that proximity to residential area is a most important factor [46].

Table 12: Weight of Criteria of the Parameters

Criteria	Weight	Weight (%)
Soil	0.044	4.35
Slope	0.054	5.43
Geology	0.066	6.58
Roads	0.042	4.19
Rivers	0.089	8.93
GWT	0.128	12.81
Residential	0.173	17.30
LULC	0.079	7.89
Water well	0.106	10.62
Reservoir	0.058	5.82
Prone areas	0.092	9.20
Pipe Line	0.069	6.88

4.1. Landfill Suitability Analysis Results

In order to select appropriate landfill site for the study area comparison of the different factors based on environmental, social, and economic impacts were done. Weighted Linear Combination result showed four classes of suitability levels. These are unsuitable, less suitable, moderately suitable, and suitable as provided in Figure 9.

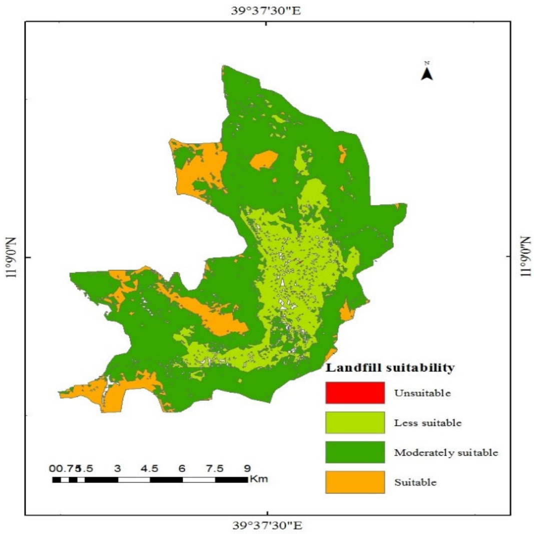

Figure 9: Landfill Site Suitability Map

The area coverage of each suitability class was calculated in the GIS environment after converting the raster map to vector. Landfill suitability and their area coverage were the Suitability class Area for Unsuitable (0.0494), Less suitable (33.35), Moderately suitable (106.87), and Suitable (19.18) in km^2. Out of the total study area, about 12.03% (19.18 km^2) fall under suitable category due to the area satisfies environmental, social, and economic criteria. These areas are preferable land for landfill because of their minimum effect on the environment, public health, and cost effective than other parts of the area. The site was found in the south and northwest parts of the study area. While 0.03% (0.0494 km^2), falls under unsuitable as the areas are environmentally unfriendly, socially unacceptable, and economically unfeasible for the landfill site. These areas found at the central parts of the study area. The moderate suitable area covers an area of 67.02% (106.87 km^2), and 20.92% (33.35 km^2) falls under a less suitable area for landfill sites.

4.2. Evaluating Candidate landfill Sites

It was advisable to first select few best ranking alternative sites on the basis of criteria such as the size of the site, the distance from the main road and the wind are the determining criteria used to evaluate landfill candidates in order to select the most suitable site [34]. The required area in this study was 1.49 km^2 for total MSW generated and 0.43 km^2 for non-recyclable solid waste. Accordingly, the analysis of the potential landfill sites in GIS environment sites with an area of less than 1.49 km^2 is excluded from further analysis. Then, the result of the study shows 3 landfill sites are selected for further evaluation. Landfill site 1 covers an area of 5.39 km^2, while landfill site 2 and 3 has an area of 3.98 km^2 and 4.58 km^2, respectively. These sites are equally the suitable site due to the size point of view. Locations of the 3 selected candidate landfill sites are shown in Figure 4.18.

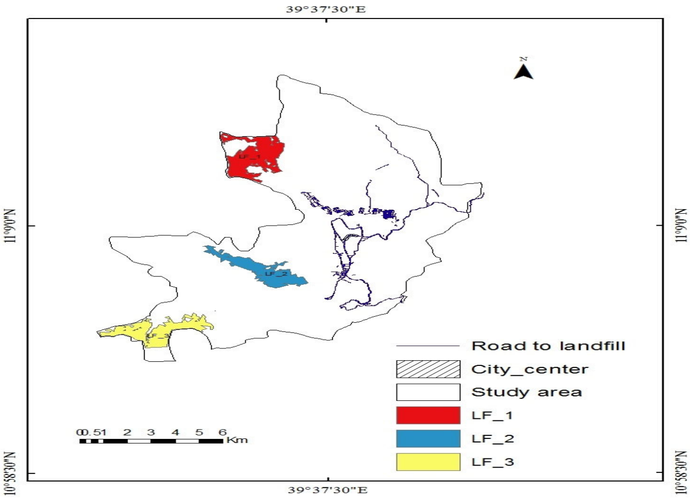

Figure 10: Candidate Landfill (LF) Sites Map

For the evaluation of landfill candidates, the distance to the city center is also an important criterion from an economic point of view. Analysis of the landfill candidates measuring the distance along the road shows that landfill 1 was 5.67 km from the center, while landfill 2 and 3 were close to 5.38 km and 9.38 km, respectively. Due to the high transport costs, landfilling far from the center of the region is not preferable [47]. So, the site with in medium distance to the center of the town is preferable than very close or far sites. Hence, from the transportation point of view, landfill site 2 is the most suitable and site 3 is the least suitable site from candidate sites.

The wind direction is also an important criterion when choosing the best landfill. In the study area, the wind predominates from the northeast, followed by northeast to western parts of the city. The blowing wind could take toxic fumes and particulate matter from landfills with it, affecting human health. Therefore, locations that are not in this wind blow from the landfill into the city [48]. Therefore, landfill 2 is the least suitable from a wind direction point of view as part of the city is exposed to the gusts of wind from the landfill, and 1, 3 are best suited because they are to the west of the city. Therefore, the criteria for choosing a landfill are complicating one another. Attempts have been made to address this challenge by simultaneously considering these two criteria through AHP (Table 13).

Table 13: Pair Wise Comparison and Criteria Weight

	Wind	Distance from city center	weight	Weight (%)
Wind	1	2	0.67	67
Distance from city center	1/2	1	0.33	33

Weights assigned to the two criteria showed wind direction to be more important than distance from the city center. Likewise, stated that wind direction has more weight than the distance from city center. The analysis of all the candidate landfill sites with respect to those evaluating criteria is shown in Table 14 [48].

Table 14: Comparison Matrices of the Candidate Landfill Sites with each of the Criteria.

	LF 1	LF 2	LF 3	Weight	Weight (%)
Wind direction					
LF 1	1	4	1	0.48	29.55%
LF 2	0.25	1	1	0.20	12.50%
LF 3	1	1	1	0.94	57.95%

Distance from center					
LF 1	1	0.33	1	0.46	36.49%
LF 2	3	1	4	0.63	49.76%
LF 3	1	0.25	1	0.17	13.75%
(Note: LF = Landfill site)					

Table 14 shows that landfill site 3 with a weight of 0.94 is the most suitable site while landfill 2 with a weight of 0.2 is the least preferred site from wind direction point of view. From the distance of city center, landfill site 2 with a weight of 0.63 is most suitable while site 3 weight of 0.17 is least suitable. To solve the complex decision problems of choosing the most suitable landfill site, all the evaluating criteria were considered by the AHP method. Then, weights for all candidate landfill sites were derived from multiplying criteria weight and landfill sites weight that are derived in relation to those criteria and then summing the corresponding products.

Table 15: Weight and Rank of the Candidate Landfill Sites

	Wind	Center of city	Weight	Rank
LF 1	19.70	12.16	0.36	1
LF 2	8.33	16.59	0.31	3
LF 3	38.64	4.58	0.33	2

The result in Table 15 indicates that landfill site 1 is the most suitable site for landfill. In addition, site 2 is the second most suitable site. The figure also shows that landfill site 1 is accessible to the existing road which makes more acceptable from economical points of view. This means the site is at a location that requires minimum transportation cost. Generally, landfill site 1 is the most suitable site for Dessie town and if it is situated in the south west direction of the town.

4. Conclusions

The objective of this study was to select the suitable solid waste disposal sites for Dessie town. Solid waste disposal site selection is one of the most significant components of waste management system. This could be realized using recent improvements in the spatial sciences via GIS and MCE techniques. To achieve the target of the study, the first step was determining the capacity of the required site by estimating solid waste generation rate and then overlay analysis of different layers were done. Therefore, the result of this study shows that the total amount of municipal waste generated in Dessie town was estimated at 98560.046 tons in 2039 with 0.45 kg/captia /day of generation rate. 1.49 km2 of landfill area is required if all waste is disposed of in landfills, while 1.27 km2 of landfill area is required for 15% of the waste is to be recycled. Twelve most important factors were considered and evaluated using MCE method. Using different datasets derived, suitability index maps for each factor were produced and combined. AHP process was applied to calculate the relative weight values of each criterion based on their relative preference and the CR which measures the consistency of the AHP results is 0.088. From the overall weights calculated, the criteria of distance to residential area, water well and groundwater-related factor are quite important criteria in siting landfill. The results of the final suitability map show 0.03% of the study area is unsuitable while 12.03% is suitable for landfill siting. The other 20.92% is less suitable and 67.02% of the study area is moderately suitable and this suitability map is supportive perhaps as initial assessment study report. Candidate landfill sites were delineated from these suitable classes based on the size of the site, wind direction and to the center of the town. Accordingly, 3 candidate landfill sites were extracted and evaluated to identify the suitable site for landfill using the comparison of weight of criteria in AHP evaluation. Landfill site 1 were the first option from the candidate which is found at the northern direction of the town namely Borumeda. Furthermore, results from this paper are relevant in the present context for the management of solid waste, planning of public health and services management of this city; in particular, the same procedure may be applied in different cities to identify the most suitable and appropriate waste [49-54].

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