Suitable Sites Identification for Solid Waste Disposal Using Geographic Information System and Analytical Hierarchy Process Method in Debark Town, Northwestern Ethiopia

Muralitharan Jothimani¹, Asmamaw Geberslasie² and Radhakrishnan Duraisamy³

1Department of Geology, Arba Minch University, Ethiopia
2Department of Geology, University of Gondar, Ethiopia
3Faculty of Water Resources and Irrigation Engineering, Arba Minch University, Ethiopia
Email: muralitharangeo@gmail.com

Abstract. Proper site selection for solid waste disposal is a significant issue in the management of solid waste. The present study has been carried out in Debark town, Amhara region, Northwestern Ethiopia, with an analytical hierarchy process (AHP) method and geographic information system (GIS) tools to locate the suitable solid waste disposal sites. In the present study, the following eleven thematic layers such as groundwater level, lithology, land use/land cover, precipitation, soil types, elevation, and slope distance from (drainages, springs, lineaments, and roads), and their sub-criteria have been used for the selection of suitable solid waste disposal sites. The above-mentioned thematic factors and their sub-criteria standardized weights and consistency ratios have been calculated and checked using the AHP method. The outcome of this study shows (2 km² area) 2.50%, (3 km² area) 3%, and (77 km² area) 94.5% of the area is highly, moderately, and unsuitable, respectively, for the siting the solid waste disposal site in the present study area. The current study results show the effectiveness of GIS tools and the AHP method in solid waste disposal site selection analysis.

Keywords. Solid waste disposal sites, AHP, GIS, Debark town, Ethiopia

1. Introduction
Managing solid waste is a major significant problem; the fast-growing population in the urban regions faces the solid waste handling issue, rising day by day [1-3]. According to [4], growing population, industrial expansion, fast and haphazard urbanization, and people's living standards are linked to solid waste production. Urban areas produce enormous solid waste, creating environmental problems [5]. Water and land resources are contaminated by leachate infiltration from the open dumpsite. A shallow groundwater table may contact the leachate produced from the decomposition of the waste [6]. There are numerous procedures involving solid waste administration, like collecting waste, transportation, waste processing, and landfilling. Landfilling, thermal treatment, and recycling are the different techniques used in solid waste management [7]. Solid waste disposal in a suitable landfill site is essential in protecting human health and the environment. In many places, the sanitary landfill is a widely accepted solid waste disposal method [8]. Solid waste disposal site choice is crucial in sanitary landfill siting.

Parameters such as fast-growing economy, societal, population growth rate, living standard developments, and government authorities' financial contributions need to be considered throughout the solid waste disposal site selection procedure [9]. Sciences, social sciences, and public health play an
essential role in the site selection procedure [10]. The usage of the disciplines mentioned above for site selection may vary upon the specific region's requirements and scenarios. Different thematic layers have been selected and superimposed over one other to recognize the overall suitability region for the waste disposal site [11-13]. Waste disposal site selection demands spatial data processing about different parameters regulating the suitability analysis [14]. Geographic Information System (GIS) tools have the competence for the spatial and attribute data assessment, analysis, and visualization in the solid waste disposal site selection process.

Slope, elevation, landslide hazard, land use/land cover, population density, endangered area, groundwater level, and distance from the surface and groundwater resources, communication lines, types and characteristics of the soil, lithological type, transportation, and distance from the built-up area have been considered for waste disposal site suitability analysis [15-18]. In those studies, authors used remote sensing data, field, and collateral data coupled with the GIS tools and techniques to find an appropriate solid waste disposal site in various parts of the world, including Ethiopia. The analytical hierarchy method (AHP) is the ideal multi-criteria decision-making (MCDM) method for solid waste disposal site selection procedure. Subsequent scholars have used GIS coupled with the AHP method to find the weights for the chosen thematic layers and their sub-criteria in the waste disposal site selection process [15, 19, 23-25].

The AHP method was introduced and advanced by Saaty [26], and it is one of the best MCDM systems. It can be used to investigate and select the alternatives highlighting many and even challenging purposes. In a complex decision-making process, the AHP method offers established and effective results. AHP can help identify and assign weights of criteria selection, data analysis and speeding up the choice-making procedure. [17, 24, 25] stated that open and random dumping of solid waste is common in many parts of Ethiopia. There is no scientifically selected proper disposal site in the present study area, debark town, Northwestern Ethiopia, facing the solid waste disposal problem. Debark town's people practice open field waste disposal, disposing of waste close to settlements and water bodies. The present study aims to select an appropriate solid waste disposal site model in Debark town, Northwestern Ethiopia, using the GIS techniques and the AHP method. There have been no such studies using this method or data from the present research area to date. Hence, the current research is the leading of its kind in the present study area. In the present study, the following eleven decision criteria have been considered to identify the suitable locations for solid waste disposal: distance from the (drainages, springs, lineaments, roads), groundwater level, lithology, land use/land cover, precipitation, soil type, elevation, and slope.

2. Materials and methods

2.1 Study area

Debark town in the Amhara region of Northwestern Ethiopia, bounded by 13° 3' and 13° 13' north latitudes and 37° 50' and 37° 57' east longitudes. The areal coverage of the present study area is 82 sqkm. Figure 1 shows the current study area's location map. The study area's minimum and maximum elevation and slope are varied from 2708 m to 3193 m above mean sea level and 0° to 49°, respectively. The annual average precipitation of the study area is 1300mm. The minimum and maximum mean temperatures are 25°C and 18°C, respectively. Ethiopia's lithology includes combining a hard-basaltic rock basement, other crystalline intrusive rocks, volcanic rocks connected with the East African Rift System, and sedimentary rocks of different geological ages [27]. From the Ethiopian Geological Survey's geological map, it has been noticed that the present study area covered Ashangi and Aiba flood basalts with different weathering natures. Furthermore, the ages of these formations are Eocene and late to middle Oligocene, respectively, and some study area portions are enclosed by recent alluvium. According to [27], the present study area is covered by clay soil followed by clay loam and silty clay.
2.2 Data Sources
Sentinel 2 satellite images with a spatial resolution of 10 m and cloud free data, dated March 8, 2019, has been downloaded from the earth explorer website. Land-use/land-cover (LULC) and lineaments have been prepared from the mentioned-above satellite image. Geology map has been prepared based on extensive field surveys and secondary maps like the Ethiopian geological survey's geological map toposheets. The current study area's road network was extracted from Google earth's image, toposheets, and 30 m spatial resolution digital elevation model called advanced space-borne thermal emission and reflection, digital elevation model (ASTER-DEM) data has been used to prepare the drainage network, elevation, and slope layers. The Food and Agricultural Organization [28] database has been used to develop the present study area's soil database. In the present study, groundwater level data and spring locations have been collected through GPS field surveys. The above thematic criteria were prepared by downloading the satellite image, scanned, georeferenced, projected the toposheets, and finally digitized the pertinent data. Also, thematic layers like distance from the road, groundwater level, lineaments, and distance from the springs and drainage layers were prepared by adopting GIS methods such as buffer, interpolation, and overlay in the Arc GIS 10.6.1 environment.

3. Methods
The present study adopted the AHP method to calculate the selected eleven thematic parameters and their sub-criteria standardized weights. The following paragraphs discuss the standard steps adopted in the present study to develop the pairwise comparison matrix, weights standardization, consistency ratio examination for the eleven thematic parameters, and their sub-criteria. The first step of the AHP process is splitting a complex issue into several more straightforward matters in a decision hierarchy [26]. The next step is constructing a pairwise decision matrix for the selected eleven thematic layers. The 9-point scale, extending from 1 (unimportance or equal significance) to 9 (absolute importance or extreme preference), was used to compare the eleven thematic layers sub-criteria in solid waste site selection. A pairwise comparison matrix has been developed. Then, the consistency ratio was calculated for all thematic layers, and the same was > 0.1; it also endorses the accuracy of the pairwise comparison matrixes developed in this present study. The steps mentioned above were followed to calculate the eleven thematic layer's sub-criteria standardized weights and the consistency ratio. The final scores were derived by multiplication the
thematic layers' weights with their sub-criteria values. Then, the same was entered into the corresponding GIS files. By adopting the weighted linear combination method, the suitable areas were identified for locating a solid waste disposal site in the present study area.

### 3.1 Thematic layers and their weights standardization

The initial relative importance weights to the selected eleven thematic layers and their sub-criteria to construct a pairwise comparison matrix based on studies conducted in Ethiopia by the following researchers [17, 24, 25], field observations, and solid waste disposal site selection guidelines released by the Ethiopian Ministry of Urban Development and Construction [29] have also been considered. Then, standardization of the thematic layers and their sub-criteria weights were carried out using AHP standard procedures. The final scores were derived by multiplying the thematic layers' standardized weights by their sub-criteria standardized weights (Table 1). Then, the final scores were entered into the corresponding GIS vector files. The vector files were converted into a raster format. The raster calculator in the ArcGIS environment was used to execute the weighted linear combination technique to get a solid waste disposal site suitability map (Figure 2).

The normalized pairwise matrix's row total was divided by the number of thematic criteria used to get the same standardized weights. In the present study, eleven thematic criteria have been used for the waste disposal site selection process in the present study. Then, to calculate the consistency vector, the pairwise comparison matrix was multiplied with the normalized pairwise matrix through the matrix multiplication method. We call the summation of the consistency vector is $\lambda$. The consistency index (CI) and consistency ratio (CR) was calculated to check the created AHP matrix, and the estimated weights were notable or consistent. The judgment matrix's consistency was tested using the consistency index (CI).

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

CI is the consistency index, $\lambda$ is the consistency vector, and $n$ is the number of thematic layers. The calculated consistency index value of the present study's thematic criteria was – 0.03.

$$CR = CI / RI$$

CR is the consistency ratio; RI is the random inconsistency value, which depends on the number of thematic criteria used [82, 83]. The CR value coefficients should not be over 0.1, representing the pairwise comparison matrix's consistency. The eleven thematic layers' consistency ratio value is 0.02. The consistency ratio value of all thematic layers and their sub-criteria does not exceed 0.1 in the present study. It also endorses the accuracy of the pairwise comparison matrixes developed in this entire analysis.

### 3.2 Sub-criteria weights standardization

The study area's drainage map was prepared using Sentinel 2 satellite image, Ethiopian mapping agency's toposheets, and ASTER-DEM. Drainages flow from the north to south direction in the present study area. Solid waste disposal sites should not be positioned close to the drainage [12, 84, 85]. Hence, the buffer analysis carried out in the ArcGIS environment for the present study area's drainage was further classified into five buffer zones (0-250 m, 25-500 m, 501-750 m, 751-1000 m, and 1001-1250 m). The maximum and minimum initial ranks have been assigned to the 1001-1250 m and 0-250 m drainage buffer categories to develop the pairwise comparison matrix, respectively, based on the literature and the Ethiopian Ministry of Urban Development and Construction [26] guidelines. Drainage's buffer normalized weights are shown in Table 1. Here consistency ratio value is 0.006.

The waste disposal site should not be positioned near the springs. The buffer analysis was carried out for the collected springs, and the same were classified into five classes: 0-250 m, 251-500 m, 501-750 m, 751-1000 m, and 1001-1500 m. The initial relative importance weights were assigned to the spring buffer classes, and a pairwise matrix was constructed. The maximum and minimum weights to the 1000-1500 m and 0-250 m spring buffer classes have been assigned, respectively, and a pairwise comparison matrix was
developed. Table 1 shows the spring buffer class's normalized weights. Here consistency ratio value is 0.051.

The groundwater level gives an understanding of the pollution hazard of groundwater to restrict anthropogenic pollution. Groundwater level data of the present study area has been collected from the dug and bore well through the fieldwork during February-2020, and the water table values ranged from 4 to 26.97 m. The water level contour was generated through interpolation techniques, and the same was converted into a polygon format in the Arc GIS environment. We classified the water level of the present study area into five categories. In the present study, deep and shallow groundwater levels are considered the most suitable and less suitable landfill sitting areas. Table 1 shows the groundwater level class's normalized weights.

The lithology of the area plays a chief role in solid waste disposal site selection. The present study area's lithological map was prepared based on the Ethiopian geological survey's geological map, Sentinel 2 satellite data, and field survey. The mapped lithological units of the present study area are namely Aiba basalt un-weathered, Aiba basalt moderately weathered, Aiba basalt deeply weathered, Ashangi basalt deeply weathered, and alluvium. Highly weathered rocks and alluvial deposits with high porosity and permeability cause leachate infiltration and groundwater contamination. Rock, which has less porosity and permeability, is highly suitable for landfill siting. We assigned the maximum rank to the un-weathered Aiba basalt, and we gave the minimum grade to the alluvial deposits. Table 1 shows the lithology classes and their normalized as well as final weights.

Lineaments are one of the good indicators of groundwater presence in any area. Lineaments may act as a channel for the leachate's more effortless flow, contaminating the groundwater system [86]. We considered the range from lineaments as one of the most significant parameters in the disposal site selection process. The present study area's lineaments were analyzed and mapped using the Ethiopian geological map, Sentinel-2 optical satellite image, advanced space-borne thermal emission and reflection radiometer (ASTER), and digital elevation model (DEM). The mapped lineaments were buffered and classified into five categories: 0-50 m, 51-100 m, 101 – 150 m, 101-200 m, and 201-250 m. The area, which is in distances between 0-50 m and 201-250 m, from the lineament, is unsuitable and highly suitable for sitting solid waste disposal sites, respectively. A pairwise comparison matrix was developed, and normalized weights were calculated for the buffered lineaments categories using the AHP method. Table 1 shows the final weights of the distance from the lineament class.

LULC analysis plays a vital role in the solid waste disposal site selection process. False-color composite has been prepared from Sentinel-2 optical satellite image, and the same has been used for extracting LULC of the present study area through supervised image classification. The LULC type of the present study area is agricultural land, barren land, bushland, forest, and settlement. The same was ranked based on its significance in siting the waste disposal site. The maximum, minimum, and between ranks were assigned to the barren land, settlement, agricultural land, bushland, and forest. Table 1 shows the final weights of the land use/land cover data.

ASTER-DEM was used to generate the present study area's slope model, and the same was classified into five slope categories such as 0 -5.780, 5.79 - 10.220, 10.23 - 15.230, 15.24 - 22.180, and 22.19 - 49.190. Steep slopes cause a flood, surface runoff, and erosion, and further, the steep slope is not an economically suitable place for siting the waste disposal site because the road and site construction cost is high. For selecting appropriate sites for landfills, the maximum and minimum weights were assigned to the 0 - 5.780 and 22.19 - 49.190 slope categories.

A suitable elevation range has to be selected to site the waste disposal site to lower the possibility of leachate percolation through the landfill column and prevent the risk of flood and erosion over the landfill location. ASTER–DEM was used to analyze the present study area's elevation, ranging from 2,708 to 3,193 m above mean sea level. The present study area's elevation values has been classified into five
categories: 2,708 - 2,803 m, 2,804 - 2,857 m, 2,858 - 2,918 m, 2,919 - 3,010 m, and 3,011 - 3,193 m. The minimum and maximum weights were assigned to the 3,011 - 3,193 m and 2,708 - 2,803 m elevation classes, respectively, and a pairwise matrix was developed, and normalized weights were calculated for the elevation class. Table 1 shows the final weights of the elevation categories of the present study area.

Rainfall is a causing factor for the movement of solid waste from one place to another place. Heavy rain causes an excessive amount of solid waste movement. The value of satellite-based precipitation products and data has already been demonstrated, especially in remote areas and hilly terrain, and where rain gauge stations are rare or completely absent [30-32]. Annual mean rainfall data has got from NASA's Tropical Rainfall Measuring Mission (TRMM), and the same has been used in the present study. TRMM precipitation data is pixel-based data with good spatial resolution. Many researchers in the past have examined the accuracy of TRMM precipitation data [33, 34]. TRMM precipitation data has been extensively used in several studies in various parts of the world, including Ethiopia, over the last few years. [35-37].

906 to 1132 mm is the minimum and maximum rainfall of the present study area. Using the ArcGIS interpolation tool, a rainfall contour map was generated and classified into five classes. During the pairwise comparison matrix development stage, the lower and high weights were assigned to the 794-906 mm and 1246-1357 mm rainfall categories. Rainfall categories and their final normalized weights were shown in table 1.

Consideration of the present study area's soil types for landfill solid waste disposal site selection is significant. The soil type controls the vertical movement of the leachate on the landfill site. Clay soil is more favorable for landfill sites because it is highly resistant by nature to leachate and is also used for sanitary landfill baselining. Besides, it favors the area with more soil thickness as it offers soil for casing solid waste after proper disposal to lessen air contamination from the landfill site. In this study, we recognized silty clay as the most suitable soil for a landfill site because of its dominance of the clay content, and also, the thickness of this soil is more significant. Clay and clay loam were recognized as suitable and unsuitable soil, respectively, for the solid waste disposal site. The present study area's soil types and their final scores have shown in table 1.

The road map was prepared from Google earth's image, and we did a buffer analysis, and the same was classified into five buffer classes. The area within 0-100m distance from the major road was not considered a suitable location for the waste disposal site. Because, If the disposal site is near the way, it may cause health issues for commuters. If the landfill site is located too far from the existing road, the cost may increase to collect and transport the waste [38, 39]. The area located between the 201-300m road distances has been considered the most suitable site in the present study area. Table 1 shows the road network classes and their final scores.

4. Results and discussions

4.1 Locations selected for the solid waste disposal site

In this present study, the weighted linear combination technique has been used to get the final solid waste site suitability map (Figure 2). The final results were classified into three categories: highly suitable, moderately suitable, and unsuitable for positioning the solid waste disposal sites in the present study area. Five highly suitable and four moderately suitable locations have been identified for placing landfill sites in the present study area. The total areal coverage of the current study area is 82 km². The outcome of this study shows (2 km²) 2.50%, (3 km²) 3%, and (77 km²) 94.5% of the area is highly, moderately, and unsuitable, respectively, for the positioning of the solid waste disposal site in the present study area.

5. Conclusion

In developing nations, suitable site selection for solid waste disposal is one of the main issues. Remote sensing data and field data, GIS tools, and AHP methods play a vital role in the disposal site selection modeling. In the
present study, we have selected eleven thematic criteria (like distance from the (drainages, springs, lineaments, roads), groundwater level, lithology, land use/land cover, precipitation, soil types, elevation, and slope) according to the study area conditions and availability of the relevant data. Initial suitable weights were assigned to the eleven selected thematic criteria. Based on earlier studies conducted in Ethiopia, their sub-criteria, fieldwork, the Ethiopian ministry's urban development guidelines and construction of the solid waste disposal site selection, and the pairwise comparison matrix were developed. The final scores were derived by multiplication of the thematic layers' standardized weights with their sub-criteria's standardized weights. The weighted linear combination technique was employed using the raster calculator in the ArcGIS environment to get a final solid waste disposal site suitability map. The total areal coverage of the present study area is 82 km². The results of this study show (2 km²) 2.50%, (3 km²) 3%, and (77 km²) 94.5% of the area is highly, moderately, and unsuitable, respectively, for the positioning of the solid waste disposal site in the present study area. The present study's outcomes can solve the problems related to locate suitable sites for solid waste disposal since the current research method is scientific. The present results may provide information to the administrators and planners of the Debark town to locate a suitable site for solid waste disposal and support them in resolving solid waste administration snags. The present study results show the GIS tools' effectiveness and the AHP model in solid waste disposal site selection model analysis.

| S. No | Thematic layer | Thematic layer's weights | Sub-criteria | Sub-criteria's weights | Final weight (Thematic layer's weights * Sub-criteria's weights) |
|-------|----------------|--------------------------|--------------|------------------------|-------------------------------------------------|
| 1     | Distance from the drainage (m) | 0.23 | 0-250 | 0.06 | 0.0138 |
|       |                 |                     | 251-500 | 0.10 | 0.023 |
|       |                 |                     | 501-750 | 0.16 | 0.0368 |
|       |                 |                     | 751-1000 | 0.26 | 0.0598 |
|       |                 |                     | 1001-1250 | 0.43 | 0.0989 |
| 2     | Distance from the spring (m) | 0.18 | 0-250 | 0.03 | 0.0054 |
|       |                 |                     | 251-500 | 0.07 | 0.0126 |
|       |                 |                     | 501-750 | 0.14 | 0.0252 |
|       |                 |                     | 751-1000 | 0.26 | 0.0468 |
|       |                 |                     | 1001-1250 | 0.50 | 0.09 |
| 3     | Groundwater level (m) | 0.14 | 4.00-8.60 | 0.03 | 0.0042 |
|       |                 |                     | 8.61- 13.19 | 0.07 | 0.0098 |
|       |                 |                     | 13.20-17.78 | 0.14 | 0.0196 |
|       |                 |                     | 17.79-22.38 | 0.26 | 0.0364 |
|       |                 |                     | 22.39- 26.97 | 0.50 | 0.07 |
| 4     | Lithology       | 0.12 | Aiba basalt unweathered | 0.56 | 0.0672 |
|       |                 |                     | Aiba basalt moderately | 0.26 | 0.0312 |
weathered Aiba & Ashangi basalt deeply weathered 0.12 0.0144
Alluvium 0.06 0.0072

5 Distance from the lineament (m) 0.10
0-50 0.05 0.005
51-100 0.08 0.008
101-150 0.15 0.015
151-200 0.27 0.027
201-250 0.45 0.045

6 Land use/land cover 0.07
Barren land 0.45 0.0315
Bush land 0.27 0.0189
Forest 0.15 0.0105
Agriculture land 0.08 0.0056
Settlement 0.05 0.0035

7 Slope (degree) 0.05
0 - 5.78 0.42 0.021
5.79 - 10.22 0.26 0.013
10.23 - 15.23 0.16 0.008
15.24 - 22.18 0.10 0.005
22.19 - 49.19 0.06 0.003

8 Elevation (m) 0.04
2,708 - 2,803 0.42 0.0168
2,804 - 2,857 0.26 0.0104
2,858 - 2,918 0.16 0.0064
2,919 - 3,010 0.10 0.004
3,011 - 3,193 0.06 0.0024

9 Precipitation (mm) 0.03
794-906 0.42 0.0126
907-1019 0.26 0.0078
1020-1132 0.16 0.0048
1133-1245 0.10 0.003
1246-1357 0.06 0.0018

10 Soil 0.02
Silty clay 0.54 0.0108
Clay 0.30 0.006
| Distance from the road (m) | Clay loam |  |  |
|---------------------------|-----------|---|---|
| 0-100                     | 0.03      | 0.0009 |
| 101-200                   | 0.07      | 0.0021 |
| 201-300                   | 0.50      | 0.01 |
| 301-400                   | 0.26      | 0.0052 |
| 401-500                   | 0.14      | 0.0028 |
| 501-600                   | 0.11      | 0.0016 |

Figure 2. Waste disposal site suitability map

References

[1] Mikkelsen P S, Häfliger M, Ochs M, Jacobsen P, Tjell J C and Boller M 1998 Pollution of soil and groundwater from infiltration of highly contaminated stormwater A case study *Water Science and Technology* 36 325–330

[2] Chaulya, S K 2003 Water resource development study for a mining region *Water Res Manag* 17 297–316

[3] Rahman M M, Sultana, K R and Hoque M A 2008 Suitable sites for urban solid waste disposal using GIS approach in Khulna City, Bangladesh. *Proceedings of the Pakistan Academy of Sciences* 45 11–22

[4] Saeed M O, Nasir M H and Mujeebu M A 2008 Development of municipal solid waste generation
and recyclable components rate of Kuala Lumpur: Perspective study *International conference on environment* (ICENV) Penang, Malaysia

[5] Abul S 2010 Environmental and health impact of solid waste disposal at mangwaneni dumpsite in Manzini Swaziland. *J. Sustain. Dev. Afr.* 12 1520–5509

[6] Bahaa-Eldin EAR, Yussof I, Abdul Rahim S, Wan Zuhairi W Y and Abdul Ghani M R 2008 Heavy metal contamination of soil beneath a waste disposal site at Dengkil, Selangor, Malaysia. *Soil Sediment Contam* 17 449–466

[7] Al-Jarrah O, and Abu-Qdais H 2006 Municipal solid waste landfill siting using intelligent system. *Waste Management* 26 299–306

[8] Mahini S A and Gholamalifard M 2006 Siting MSW landfills with a weighted linear combination methodology in a GIS environment. *Int. J. Environ. Sci. Technol* 3 435–445

[9] Javaheri H, Nasrabad T, Jafarian M H, Rowshan G R, and Khoshnam H 2006 Site selection of municipal solid waste landfills using analytical hierarchy process method in a geographical information technology environment in Giroft Iran. *J Environ Health Sci Eng* 3 177–184

[10] Chang N, Parvathinathan G and Breeden J B 2008 Combining GIS with fuzzy multi-criteria decision-making for landfill siting in a fast-growing urban region *J of Envi Manag* 87 139–153

[11] Chang N B and Pires A 2015 *Sustainable solid waste management: A systems engineering approach* Published by Wiley

[12] Torabi-Kaveh M, Babazadeh R, Mohammadi S D and Zaresefat M 2016 Landfill site selection using combination of GIS and fuzzy AHP a case study Iranshahr Iran *Waste Manag Res* 34 438–448

[13] Demesouka O E, Anagnostopoulos K P and Siskos E 2019 Spatial multi criteria decision support for robust land-use suitability the case of landfill site selection in Northeastern Greece *Eur J Oper Res* 272 574–586

[14] Ojha C S P, Goyal M K and Kumar S 2007 Applying fuzzy logic and the point count system to select landfill sites *Environ Monit Assess* 135 99–106

[15] Tirusew A E and Amare S M 2013 Solid waste dumping site suitability analysis using geographic information system (GIS) and remote sensing for Bahir Dar Town, *African Journal of Environmental Science and Technology* 7 976-989

[16] Hamzeh M, Abbaspour R A and Davalou R 2015 Raster-based outranking method: a new approach for municipal solid waste landfill (MSW) siting *Environ Sci Pollut Res* 22 12511–12524

[17] Genemo B and Yohanis B 2016 Municipal solid waste disposal site selection of Jigjiga town using GIS and remote sensing techniques Ethiopia *International Journal of Physical and Human Geography* 4 1-25

[18] Umit Y and Cuneyt G 2016 Identification of suitable future municipal solid waste disposal sites for the Metropolitan Mersin (SE Turkey) using AHP and GIS techniques *Environ Earth Sci* 75 101

[19] Donevsksa K R, Gorselvski P V, Jovanovski M and Pesevski I 2012 Regional non-hazardous landfill site selection by integrating fuzzy logic AHP and geographic information systems *Environ Earth Sci* https://doi.org/10.1007/s12665-011-1485-y

[20] Khan D and Samadder S R 2015 A simplified multi-criteria evaluation model for landfill site ranking and selection based on AHP and GIS *J Environ Eng Landsc Manag* https://doi.org/10.3846/16486897.2015.1056741

[21] Kahraman C, Keshavarz G M, Zavadsaks E K, Onar S C, Yazdani M and Oztaysi B 2017 Intuitionistic Fuzzy EDAS method an application to solid waste disposal site selection *J Environ Eng Landsc Manag* 25 1–12

[22] Victor F N, Anahi C S, Pedro R A, Jean PH and Nazli Y 2017 Modeling environmental susceptibility of municipal solid waste disposal sites: a case study in São Paulo State Brazil *J
Geogr Inf Syst 9 8–33

[23] Al-Anbari M A, Thameer M Y and Al-Ansari N 2018 Landfill site selection by weighted overlay technique: case study of Al-Kufa, Iraq Sustainability 10 999

[24] Duguma E, Tesfaye F, Amaha K and Abel B 2018 Municipal solid waste generation and disposal in Robe town Ethiopia Journal of the Air & Waste Management Association 68 1391-1397

[25] Semaw F 2018 The Problem of Solid Waste Site Selection in Woldia Town J Remote Sens GIS 7 246

[26] Saaty T L 1980 The analytic hierarchy process: planning, priority setting, resource allocation (decision making series) McGraw-Hill New York

[27] Smedley P 2001 Groundwater quality: Ethiopia. British Geological Survey, p 6

[28] FAO 2006 World reference base for soil resources: a framework for international classification, correlation, and communication, 2006th edn. Food and Agriculture Organization of the United Nations, Rome

[29] EMUB&C (2012) Solid Waste Management Manual: With Respect to Urban Plans, Sanitary Landfill Sites and Solid Waste Management Planning

[30] Feidas H, Kokolatos G, Negri A, Manyin M, Chrysoulakis N and Kamarianakis Y 2008 Validation of an infrared-based satellite algorithm to estimate accumulated rainfall over the Mediterranean basin Theor Appl Climatol 95 91–109

[31] Michaelides S, Levizanni V, Anagnostou E, Bauer P, Kasparis T and Lane J E 2009 Precipitation: measurement remote sensing climatology and modeling Atmos Res 94 512–533

[32] Nastos P T, Kapsomenakis J and Douvis K C 2013 Analysis of precipitation extremes based in satellite and high-resolution gridded data set over Mediterranean basin Atmos Res 131 46–59

[33] Heiblum R H, Koren I and Altaratz O 2011 Analyzing coastal precipitation using TRMM observation Atmos Chem Phys 11 13201–13217

[34] Liu Z 2015 Evaluation precipitation climatology derived from TRMM multi-satellite precipitation analysis (TMPA) monthly product over land with two gauge-based products Climate 3 964–982

[35] Stisen S and Sandholt I 2010 Evaluation of remote-sensing-based rainfall products through predictive capability in hydrological runoff modeling Hydrological Processes 24 879–891

[36] Bitew M M, Gebremichael M and Gebremichael L T 2011 Evaluation of high-resolution satellite rainfall products through streamflow simulation in a hydrological modeling of a small mountainous watershed in Ethiopia Journal of Hydrometeorology 13 338–350

[37] Jiang S, Ren L L and Hong Y 2012 Comprehensive evaluation of multi-satellite precipitation products with a dense rain gauge network and optimally merging their simulated hydrological flows using the Bayesian model averaging method Journal of Hydrology 452/453 213–225

[38] Allen B G, Caetano P, Costa C, Cummins V, Donnelly J, Koukoulas S, O'Donnell V, Robalo C and Vendas D 2003 A landfill site selection process incorporating GIS modeling. In: Proceedings of Sardinia Ninth International Waste Management and Landfill Symposium, Italy

[39] Karimi H, Amiri S, Huang J and Karimi A 2018 Integrating GIS and multi-criteria decision analysis for landfill site selection, case study Javanrood County in Iran Int. J. Environ. Sci. Technol. https://doi.org/10.1007/s13762-018-2151-7