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Selection of the final solid waste disposal site in the Bolgatanga municipality of Ghana using analytical hierarchy process (AHP) and multi-criteria evaluation (MCE)

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ABSTRACT

The various components of Municipal Solid Waste (MSW) such as collection, sorting, transportation, and disposal have their peculiarities and challenges. However, final disposal sites, generally referred to as landfill sites, present a complex difficulty. The aggregation of the problems of other components has consequences on the microenvironment, public health, and groundwater. Final disposal of MSW, site selection, and management presents an enormous burden for most Metropolitan, Municipal, and District Assembly (s) in Ghana. The case of Bolgatanga Municipality is similar to many others in the Upper East region in particular and Ghana as a whole. The existing landfill site is improperly sited and poses a great danger to adjoining communities. In this work, we used the Analytical Hierarchy Process (AHP) in a G.I.S. suite and Multi-Criteria Evaluation to assess the current location and select a possible new site within the municipality. The criteria used are generally environmental and socio-economic parameters, including; distance from major roads, rivers, settlements, and the selection of an appropriate slope and soil type that suits the guidelines for the siting of a landfill. The outcome of this multi-criteria assessment is the selection of a new site far from the current disposal site indicating the inappropriate location of the current site. A combination of all weighted criteria through a model builder process produced a suitability index map for candidate landfill sites. The selected site at Sherigu is about 16 km by road from the proposed site, which is much bigger than the threshold of 500 sq. meters. The separation distance and size between the current and the proposed site are indications of how economically and environmentally inappropriate the Sherigu site is and the need for a better site that is better situated for socio-economic and environmental considerations.

1. Introduction

The management of solid wastes generated in urban regions of developing countries has been a challenge for major towns and cities. The World Bank in the year 2020, estimated an annual global solid waste of about 2.24 million metric tonnes of solid waste representing a per capita or footprint increase of about 0.79 kg per person per day. This is expected to increase daily per capita solid

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waste by 40%, resulting in about 516 million tonnes per year by 2050 for sub-Saharan Africa [1]. This situation would pose a significant challenge for municipal authorities charged with the management of solid waste. Ghana and the Bolgatanga Municipality in particular, would be no exception to the above scenario as there are serious challenges to the management of the final disposal site under limited budgetary constraints [2,3].

The efficient management of Municipal Solid Waste (MSW) gives a very positive public health outlook. There are numerous public health problems arising from poor solid waste management, particularly with improper landfill sitting [4]. Health issues arising from waste management include water, soil, and air contamination. Dains choked by municipal solid waste result in flooding and other standing waters which favour cholera and other vector-borne diseases such as malaria and dengue. Additionally, e-waste causes multiple adverse health and developmental impacts, especially in young children. More specifically, Vinti et al. [5], have catalogued the health impacts and proximity of municipal waste landfills to show; the risk of congenital anomalies with an index of the geographic density of landfill sites (within 2 km from landfill), Hydrogen sulfide (H_2S), odour, and health outcomes in a community living close to a landfill. Additionally, other health problems with wrong sitting of landfill sites include; Particulate Matter ($PM_2.5$) concentration and its association with lung function patterns, risk of giving birth to a child with Down syndrome, Congenital anomalies, cardiovascular and nervous systems impairment from a maternal residence in the function of distance from landfills. Moreover, landfill sites have been associated with; respiratory symptoms, H_2S exposure and mortality (both natural and cause-specific). Lastly, living close to a landfill site has been associated with increased hospital admissions for cardio-respiratory diseases, increased risk of births with at least one congenital malformation in a population living within 2 km of landfill sites [5,6].

Despite the numerous processes applied to manage waste, including source reduction, recycling, and waste transformation, locating a suitable site for final deposition is fundamental [7] as there are always significant quantities of waste left behind. There is therefore, the need to implement a relatively effective and efficient landfill location and management system [8], which emphasises on health risks [9] as well as the economic cost of transportation and eventually payment for sanitary services [10]. The consideration of a suitable final solid waste disposal site goes beyond environmental factors and considers several other socio-economic variables which would require some weight indexing and ranking [3,4,11].

Inappropriate and improper siting of landfills could cause pollution of the environment [12], thus, a well-designed siting technique involving both experts and stakeholders is essential [13]. Engineered landfills were first introduced in Ghana in the year 1994, under the Local Government Development Project Urban 3. This was to assist in the sustainable disposal of solid wastes which could not be recycled, composted, combusted, or processed. Under the project, moderately engineered final disposal sites were developed in some 11 district capitals. An expanded project covering the 5 largest cities (Accra, Tema, Sekondi-Takoradi, Kumasi, and Tamale) was also undertaken in the year 1995 to handle the increasing volume of waste which is a result of the increasing population.

Increasing population growth, urbanisation, as well as per capita income result in increased generation of municipal solid waste [2]. Hence, the difficulty in its management [1,14,15]. The effect of improperly managing waste, particularly solid waste, is diverse. This includes contamination of soil and water, pollution of the atmosphere, damage to environmental health and its aesthetic value [16,17] as well as their associated effects on animal and human health [18,19]. Processes involved in proper waste management range from storage, collection, transformation, and treatment to final disposal [18,20]. This research work on assessing and selecting the best site is essential as about 80% of all landfill sites in Sub-Saharan Africa are improperly sited and have the major attribute of uncontrolled dumping and semi-controlled facilities [21].

Many urban centres in the developing world with sprawling metropolis and increasing population sizes like the Bolgatanga Municipality are faced with financial and technological challenges which limit their ability to effectively manage their generated solid wastes [2]. These challenges specifically include the lack of storage receptacles, inadequate supply of vehicles for transfer and transportation, and the limited number of suitable sites for final disposal and/or treatment. At present, the only available disposal site in the Bolgatanga Municipality is an open dump site, highly inadequate to contain the large quantities of waste generated within the municipality and of great environmental nuisance to residents who live close to the site [2]. This study, therefore involved a rigorous identification and selection of a final waste disposal site considering not only environmental factors but also socio-economic considerations and how the current disposal site fits into these new standardised parameters of assessment. This, it is hoped, would bring a general improvement in the problem of solid waste disposal in the municipality and the region as a whole.

The choice of Bolgatanga for this research in the Upper East region is solely because of its status as the regional capital but also the most urbanised city with a high population density and high per capita waste generation [2,3]. Additionally, its location in a central position of the region, connecting all transport routes to the rest of the districts and to neighbouring countries of Burkina Faso and Northern Togo makes it an imperative selection for this endeavour.

A site analysis model using G.I.S. and the Multi-Criteria Evaluation (MCE) tool was used [8,22,23]. In Ghana, many similar studies in the application of G.I.S. and Multi-Criteria Evaluation (MCE) and/or selection have been done in towns, cities, and districts such as Obuasi [24], Wa [25], Accra [26–28], Tarkwa [29], Kumasi/KNUST campus [30,31], Northern Ghana [32], Sagnarigu District [33], and Tamale [19,34]. However, this study differed from the above studies because it looked at (1) assessing the suitability of the current dumping site, (2) the selection of a new site using AHP, (3) developing a set of environmental and socio-economic criteria and (4) assigning weight to the criteria to suit the local conditions with a pair-wise ranking. The relevance of this study is to provide a framework to assist the Local planning authority(s) to do the selection of landfill sites. This is from the background of most selections that are based on supposed wastelands and wetlands.

2. Materials and methods

2.1. Study area

Bolgatanga, as a municipality was established in 2004 by Legislative Instrument (L.I.) 1797 (2004) under the development decentralization policy, started in 1988. It is centrally located in the Upper East Region (Fig. 1) and serves as the administrative capital of the region bordered by Bongo District to the north, Talensi District to the south, Nabdam District to the east, and Kassena-Nankana municipality to the west. It is one of the 15 districts/municipalities which constitute the Upper East region. According to the census report of 2021, with a total land area of 729 km^2, the Bolgatanga municipality has over 2012 settlements and a population of about 139,864 made up of an urban and rural population of 89,255 and 50,609 respectively. This represents about 10.7% of the population of the Upper East Region (1,301,226). The area is characterized by slopes ranging from 1° to 5° with limited rock outcrops and few uplands having more than 10° of slope [11,35].

The current dump site in Sherigu was estimated to generate 22, 186 metric tonnes of waste annually in 2010 [36] and this figure is projected to double by the year 2025. This figure excludes those burned or buried by households. It is accessed by a single road with an unpaved surface. This compounds the difficulty of trucks accessing the site, especially in the rainy season. The site is not engineered and waste is dumped haphazardly to be burned later.

2.2. Datasets and tools

The datasets used for this work were grouped into physical and socio-economic data. The criteria selected were based on local guidelines including [37], landuse and spatial planning authority rules, other universal sources like the USEPA guidelines, and the peculiar characteristics of the study area. The following five (5) socio-economic criteria (Table 1), acquired from different sources were selected for assessment: surface water (river), slope, soil, settlement (industrial/urban, and towns/villas), and roads. The land-use/landcover of the study area was also assessed. The ArcG.I.S. ® Software was further used to prepare the map layers of all parameters. The acquisition of both raster and vector datasets is outlined in Fig. 2, while Fig. 3 shows the flowchart methodology adopted in this study.

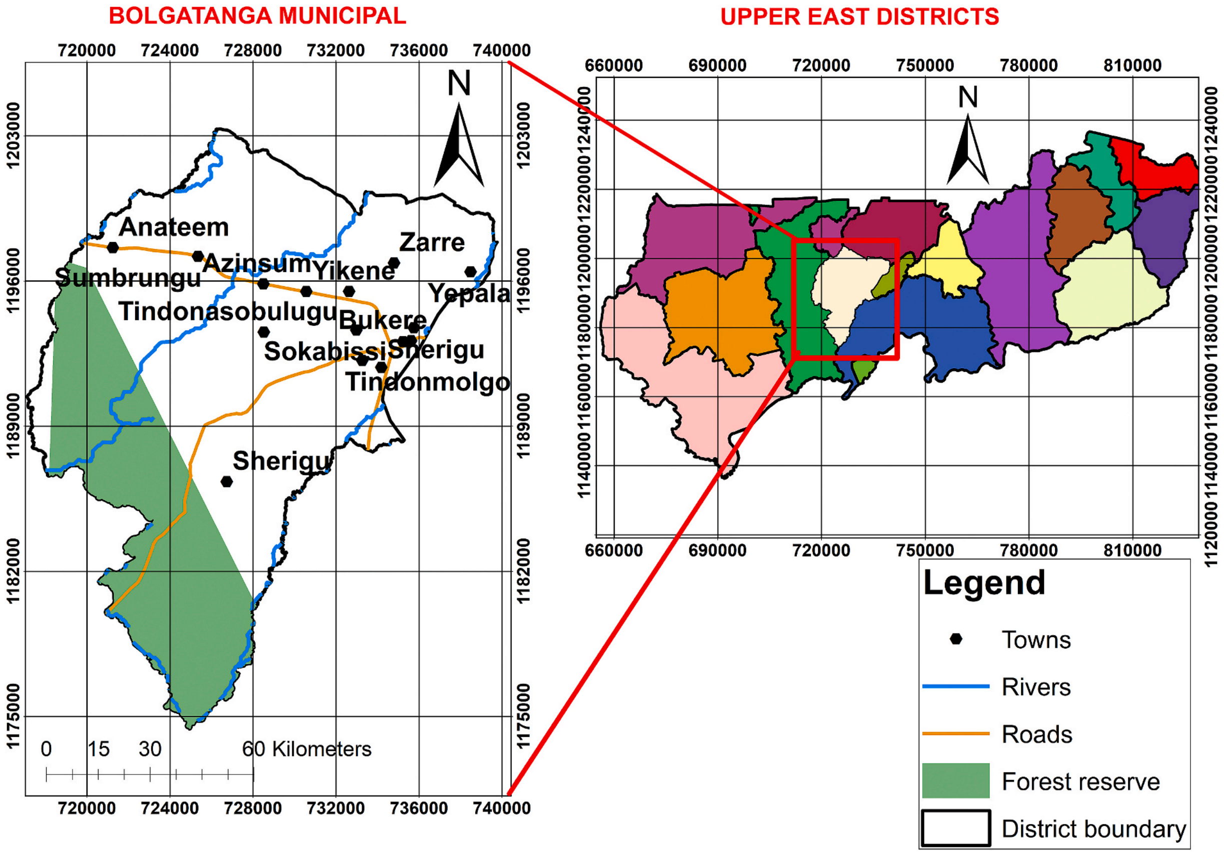

Fig. 1. A map of Bolgatanga Municipality showing the major towns, forest reserve, roads, and river network. (A) Showing the location of the current landfill site and (B) showing the proposed site (B).

Table 1
Datasets and their sources.

Data Types	Source	RESOLUTION (meters)
Towns	Country shape files (Ghana)	50 × 50
Rivers	Digital Elevation Model (DEM)	100 × 100
Roads maps	Country shape files (Ghana)	100 × 100
Landuse/landcover	ESACCI-LC-C2	20 × 20
Slope	ASTER DEM (USGS)	120 × 120
Soil data	Country shape files (Ghana)	120 × 120

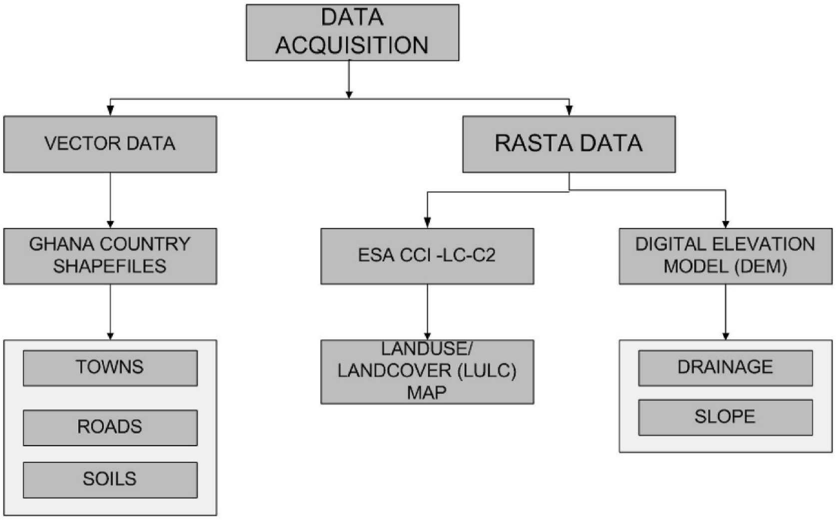

Fig. 2. Flowchart of data acquisition.

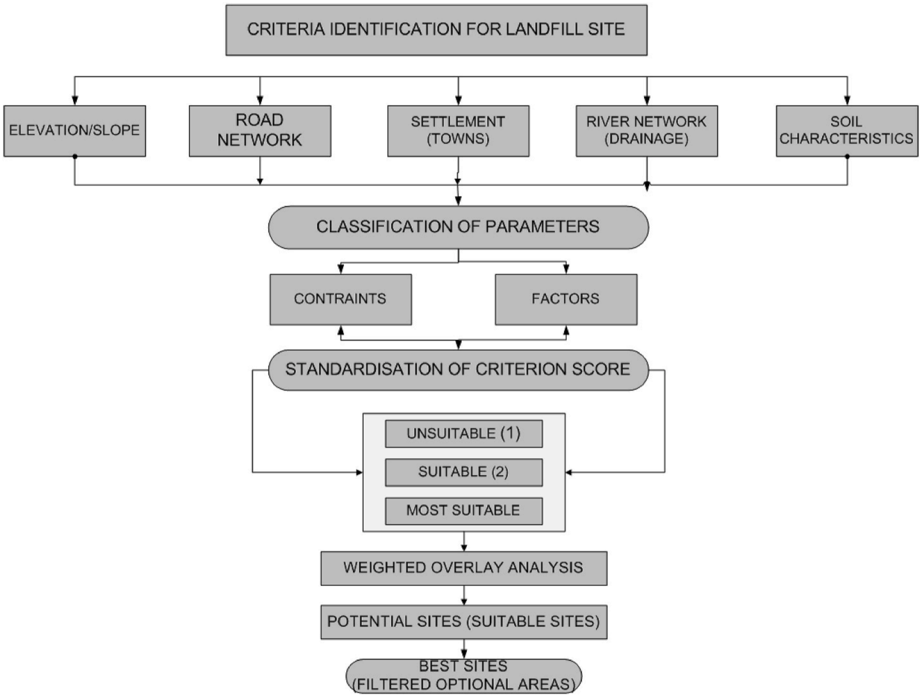

Fig. 3. A flowchart of the method used in the study.

2.3. Data Analysis

The defined standardisation for assessment is a procedure to reclassify esteems into states of set membership, involving standardised factors using fuzzy set membership functions on either a 0–1 real number scale or a 0–255 bit scale [38]. The higher estimation of the standardised scale speaks to the instance of being bound to have a place in the choice set and the other way around. To build a G.I.S. database, the various criteria are standardised to a typical scale and then integrated into the G.I.S. environment using the Spatial Analyst tool found in ArcG.I·S.® (Fig. 2).

Euclidean distance is simply the straight-line distance between two points in space. The rivers and streams, settlements, and roads in the study area were buffered to suitable distances based on literature and local standards [7,29,37]. The buffer distance was used as a restraint in other to preserve the ecological integrity of the river and protect communities from the effects of pollution and nuisance from the landfill site (Table 2), A Digital Elevation Model (DEM) of the study area was used to create a slope map. Regions described by flat gradients under 2% and/or by steep gradients of more than 10% are hazardous and not suitable for siting a landfill [37]. The study, therefore considered regions with a gradient between 2% and 10% to be more suitable and appropriate for siting the landfill. Five (5) soil types were identified in the study area, including Leptosols, Lixisols, Luvisols, Gleysols, and Fluvisols. Each soil type was ranked for its suitability in siting a disposal site based on its physical and/or chemical properties. Luvisols are high in clay content and so are more suitable for waste disposal. Clay can limit the potential infiltration of leachate, thus reducing groundwater pollution. Lixisols have low clay content and are highly leached. Leptosols are mostly found in hard rocky areas and so leachate infiltration is limited to no fractures. Gleysols are continuously water-saturated within 50 cm from the soil surface, which is a bad indicator for a landfill site as groundwater pollution will easily occur. Fluvisols are highly stratified. This influences water movement through the soil [39].

The Analytical Hierarchy Process (AHP) is one of the most popular and widely used multi-criteria evaluation tools used to determine the relative weights of the importance of each criterion based on the pairwise comparison (Fig. 3) [40–42]. A matrix is generated where each criterion is compared with the other relative to its importance on a scale of 1–9 [7]. AHP is an effective approach to obtaining the relative importance of weights of the identified criteria. A consistency ratio (CR) of the matrix is computed from the weights, based on equations (1) and (2), to ascertain the consistency of the comparison [43]. The ranking of the roads, towns, rivers, and slope and their corresponding weights is provided in Table 3. The calculated CR ratio was −0.05, which is less than the threshold value of 0.1. The comparison was therefore considered consistent.

$$\mathrm{CR} = \frac{Consistency\ Index\ (CI)}{Random\ Consistency\ Index\ (RI)} \tag{1}$$

$$\mathrm{CI} = \frac{\lambda\ \mathrm{max} - \mathrm{n}}{\mathrm{n} - 1} \tag{2}$$

Where $\lambda_{\max}$ is the principal Eigen value and n is the number of factors.

The pairwise comparison was based on the intensity of importance from 1 to 9, with 9 being a measure of extreme importance and 1 being of low or equal importance. A summary of the weights is given as; Equal importance (1), Equal to Moderate importance (2), Moderate (3), Moderate to Strong importance (4), Strong importance (5), Strong to Very strong importance (6), Very strong importance (7), Very Strong to Extremely strong importance (8) and Extreme importance (9).

The weighted overlay tool in ArcG.I·S.® was used to determine the final appropriate sites for solid waste disposal. The overlay tool allows for the combination of map layers to produce a composite suitability map based on the weights of influence from the pairwise comparison matrix (Table 3). A suitability index map showing the value of each pixel is therefore generated. This value indicates the suitability of that location for a solid waste disposal/landfill site. Areas with pixel values of 3 were considered the most suitable; a value of 2 was suitable; and a value of 1 was unsuitable. The selection of attributes and location tools were then applied to determine the final most suitable sites which meet the land size requirement of 0.5 km^2, and are also not in conflict with the current land use (Fig. 3).

The computation of weights involves three steps. The first step is the summation of the values in each column of the matrix. Then, each element in the matrix should be divided by its column total (the resulting matrix is the normalized pairwise comparison matrix. Then, the computation of the average of the elements in each row of the normalized matrix is made by dividing the sum of normalized scores for each row by the number of criteria. These averages provide an estimate of the relative weights of the criteria being compared. The Estimation of the consistency ratio (CR) is to determine if the comparisons are consistent or not. It involved the determination of the weighted sum vector by multiplying the weight for the first criterion times the first column of the original pairwise comparison matrix. This is followed by the multiplication of the second weight with the second column. The third criterion times the third column of the original matrix finally sums these values over the rows.

Table 2
Table showing the buffer distances used for each criterion.

Criteria	Buffer distance (m)
Rivers and Streams	500
Settlements	5000
Roads	1000

Table 3
Pairwise comparison matrix.

Criteria	Towns	Roads	Rivers	Slope	Soil Type	Weight
Towns	1	4	7	5	2	1.9
Roads	1/4	1	1	3	5	1.0
Rivers	1/7	2	1	6	7	1.7
Slope	1/5	1/3	2	1	5	0.8
Soil Type	1/2	1/4	1/7	1/5	1	0.2

3. Results and discussion

Multi-Criteria Evaluation and G.I.S. examination and overlay process were conducted for all constraints and criteria. Suitability maps were made for different criteria demonstrating unsuitable, suitable, and most suitable land zones. The classified layers were overlaid on one another in a G.I.S. domain utilizing their overall weights of importance from the pairwise matrix and the last composite suitability map acquired.

Landfills are high sources of pollutants and as such should not be situated close to water sources as they have a high probability of polluting waterbodies via leachate and surface runoff. The E.P.A. guidelines [37], strongly specify that a waste disposal site should not be located near rivers and streams. A 500-m buffer zone was therefore created around streams and rivers in the study area. Fig. 4(A) shows different areas within the study area assigned different classes/ranks depending on their distances to streams and rivers. Regions closest to rivers and/or streams (0 m–163.87 *m*) were assigned the lowest rank of 1 signifying their unsuitability for siting a landfill. Regions between 163.87 *m* and 327.74 *m* away from streams and rivers were assigned a rank of 2 to show they are moderately suitable for landfill siting, while farther areas, 327.74–491.6 *m*, and beyond 500 *m*, were considered the most suitable, and hence assigned a rank of 3 (Table 4).

The proximity of the landfill to the road network plays a significant role in the identification of solid waste disposal sites [44]. Although predetermined, the optimal distance of a landfill to an access road is crucial. Landfills ought to be close to already existing access roads to limit the cost of their development and running costs. It should not be far from the point of generation and easily accessible by road in the other to prevent the possibility of accidents and hazards of fire as well as limiting the cost of transportation. Fig. 4(B) shows all major road networks buffered by 1,000 *m*. Areas that are 0–332.27 *m* away from roads within the study area were ranked 1 and designated as unsuitable. Areas between 332.27C and 664.53 *m* away were classified as suitable and ranked 2. Likewise, areas that were 664.53–996.80 *m* away from the roads were considered the most suitable areas for siting a landfill (Fig. 4(B)). Though, accessibility contributes to reducing travel time and cost, in the context of a developing country such as Ghana, very close proximity to a road network would bring a lot of developmental challenges. This is because settlements are developed linearly along major roads. Most road networks in an urban area are also settlement locations. We chose to avoid a situation of sitting the landfill site close to settlements by avoiding proximity to roads.

The map in Fig. 4 (B) distinguishes areas that are unsuitable for situating a landfill and additionally serves to show that according to

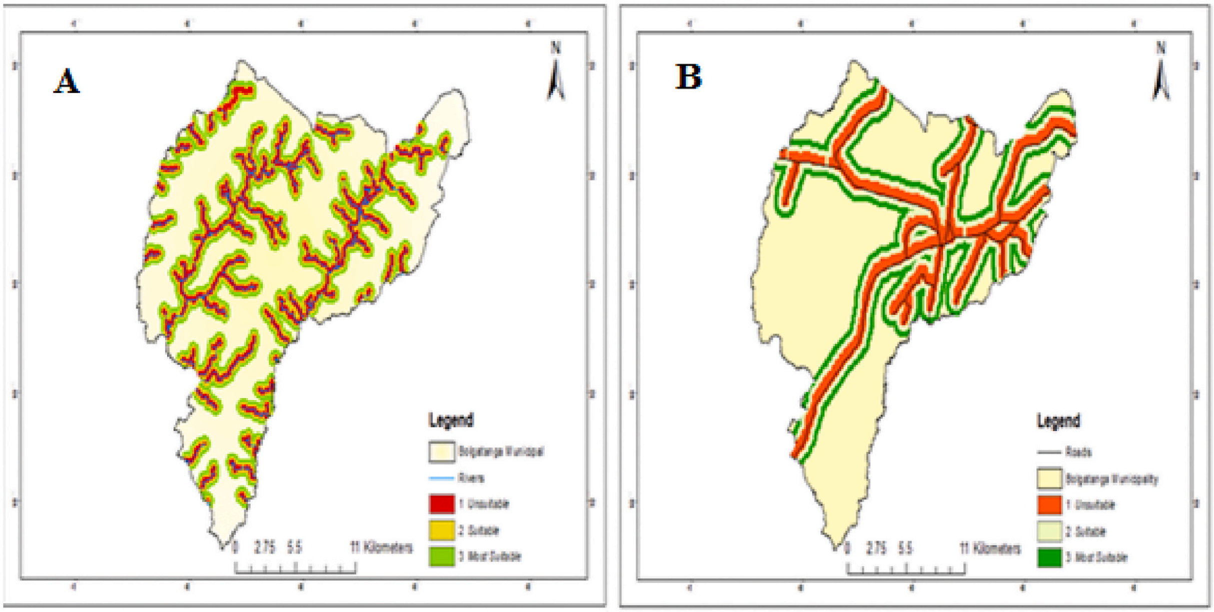

Fig. 4. Buffered rivers (Left - A) and Buffered Roads (Right - B).

Table 4
Suitability to streams and rivers.

S/N	Distance from rivers (m)	Ranking	Suitability
1	0–163.87	1	Unsuitable
2	163.87–327.74	2	Suitable
3	327.74–491.62	3	Most suitable

the road network zones, the current dumpsite is within a non-acceptable zone. Zulu et al. [45], have emphasised that it is economically advisable for landfills to be located near the point of generation and should also have easy access. This precaution will help avoid the need to construct new access roads and reduce travel time. It also reduces the frequent breakdown of hauling trucks caused by the poor nature of roads. Therefore, reasonable proximity to these transport routes reduces the cost of maintenance and will go a long way to improve the finances of the municipality. This consideration is negated by the proximity of settlements that suffer from the ill effects of landfill sites.

Similarly, zones between 0 and 1666.26 *m*, 1666.26–3332.52 *m*, and 3332.52–4998.77 *m* away from towns were classified unsuitable, suitable, and most suitable respectively (Fig. 5(A)). Ampofo et al. [25] recommended that the slope range of an area appropriate for siting a landfill ought to be between 8 and 12%. The Ghana Environmental Protection Agency guidelines [37] propose an inclined slope of 2–10% as appropriate for siting a landfill. In the study, a slope gradient ranging between 0.87 and 2.43% was therefore considered not suitable, 0.49–0.87% slope gradient was considered suitable, while areas with a gradient between 0.49 and 1% were considered the most suitable areas. Invariably, the terrain of the study area entirely had a very low slope. The slope was therefore not a significant element as all three identified fell within acceptable limits recommended in the literature [37]. Fig. 5 (B) shows the various classes of slope within the study area and Fig. 6 (A) shows the five (5) different soil types which characterize the study area. Based on the chemical and physical properties of these soils, they were ranked and classified as either unsuitable, suitable, or most suitable (Fig. 6 (A)**).** In this study, Luvisol-covered areas were considered the most suitable areas and therefore ranked 1, whereas areas covered with gleysol soil type were ranked 5 as the least suitable zone for solid waste disposal.

A combination of all weighted criteria through a model builder process produced a suitability index map for candidate landfill sites. This model was constructed using the spatial analyst tool in ArcGIS® 10.3. All input data are produced, using output layers, including distance to roads, slope, distance to towns, etc. The conditional toolset (con) was further applied, thereby allowing sites with a suitability value of three (3) to be maintained while sites with values of less than that were classified as 'No data'. In all, four classes of candidate sites were identified. They include restricted area (ranked 0), unsuitable area (ranked 1), suitable area (ranked 2), and most suitable area (ranked 3) (Fig. 6 (B).

From the weighted overlay outcome, the potential sites were extracted for more analysis. This included areas with very small sizes but still classified as potential sites. The majority filter tool in the ArcGIS® environment was used to filter out those insignificant areas to get a more refined outcome as represented in Fig. 7. This produced three potential sites, but a site less than 500, 000 sq metres was rejected.

The most suitable of the three sites was selected using the Model builder in ArcGIS (Fig. 8).

ArcGIS 10.3.1® was used to build a new model as a future reference for waste disposal site suitability analysis. The environmental setting was specified for the process, data layers were derived such as; slope, soil type, distance to towns, distance to rivers, and

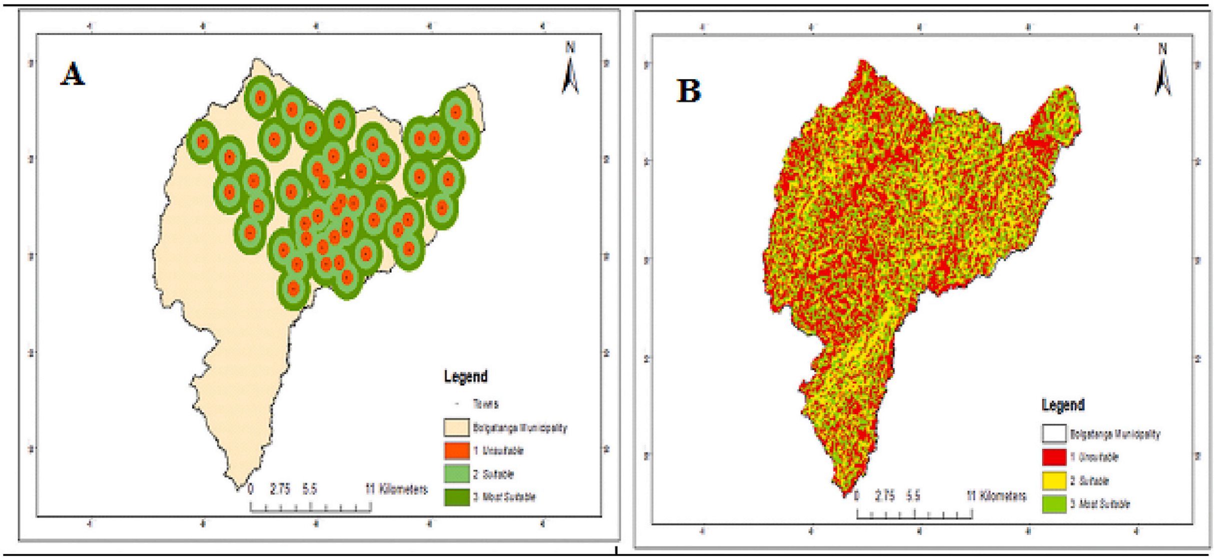

Fig. 5. Buffered towns (A) and Slope suitability map (B).

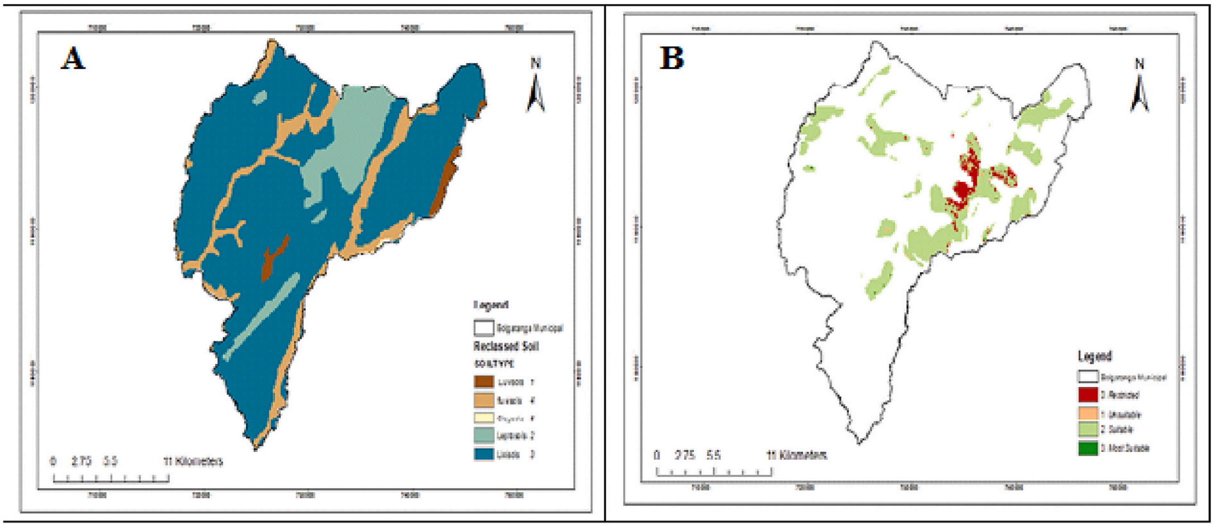

Fig. 6. Soil suitability Index (Left - A) and Aggregate Suitability Index (Right – B).

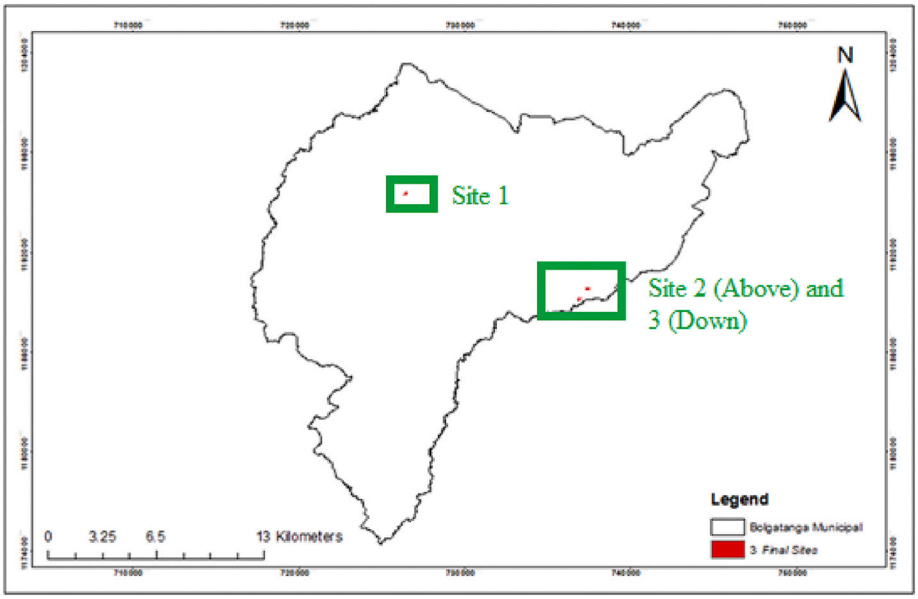

Fig. 7. Final sites.

distance to roads (Fig. 8). The data layers were then reclassified to a common scale; Most suitable (MS), Suitable (S), and Unsuitable (US). The weighted overlay and Con tools were used to assign their various weights and overlay them to obtain the suitable areas and subsequently the extraction of suitable of the only suitable area. Site 2 (Fig. 7) was the selected site from the model builder and majority filtering process. This site is most convenient considering that the previous site was close to a river and a protected forest reserve. Secondly, the closeness of the site to the adjoining district of Talensi would mean that both districts could utilize the site when developed and bear a much lower management cost. The current site is about 16 km by road to the proposed site, it also has a much smaller size which is less than the prescribed 500, 000 sq. meters.

4. Conclusions

Mostly, in Ghana, lands not suitable for agriculture and housing were generally seen as wastelands and became targets of indiscriminate and unofficial dumping. Most wetlands, for example, were used as wastelands and became receptacles for municipal urban waste. This is the case for the selection of landfill sites in many districts.

Improper solid waste disposal sites pose enormous environmental and socio-economic challenges due to the composition and

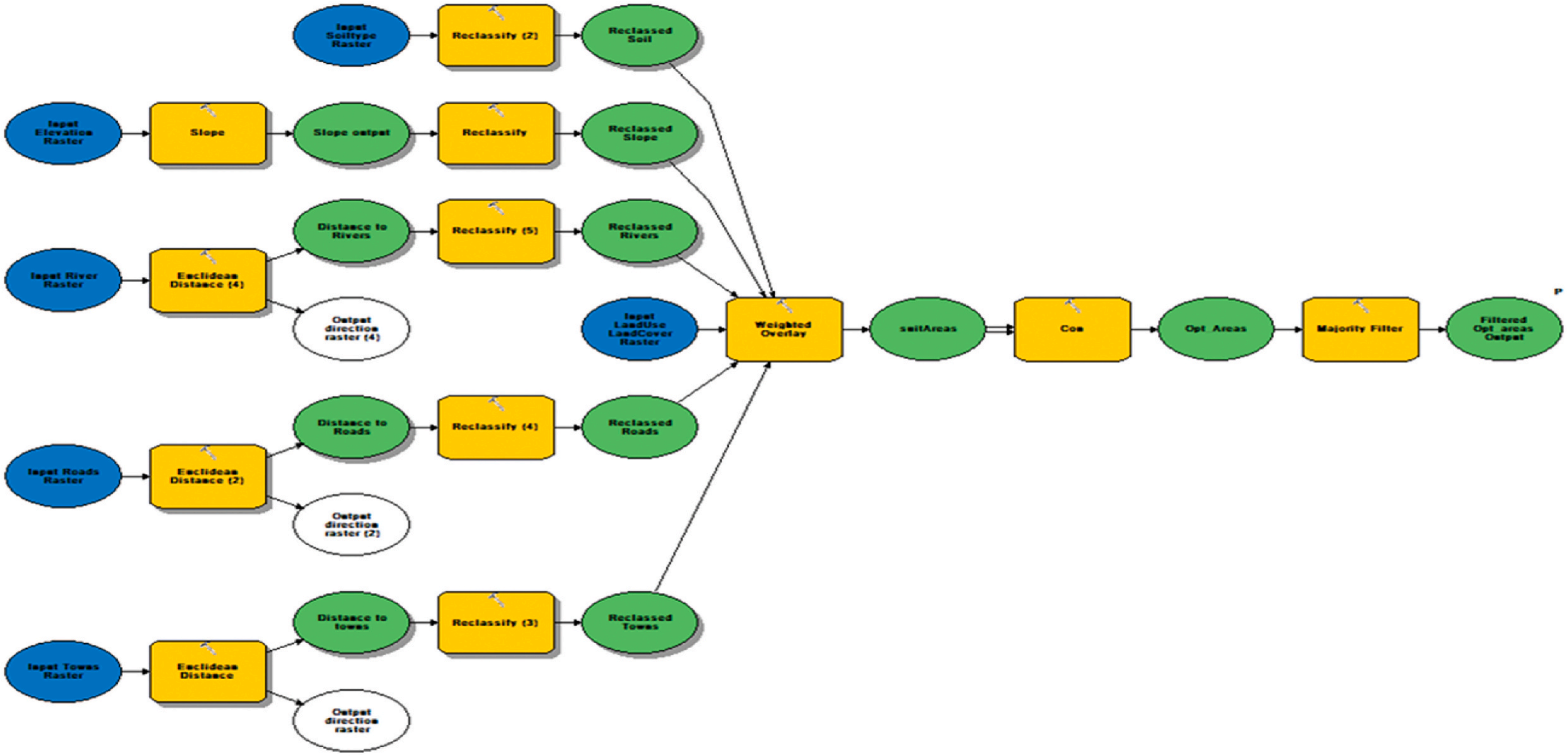

Fig. 8. Model builder for selection of final site.

complexity of the solid wastes. Thus, solid wastes should be properly managed to mitigate the threats they pose. However, in most low- and middle-income countries, selecting suitable sites for proper waste disposal can be challenging and expensive. The section of suitable sites requires the evaluation and integration of several physical, environmental, social, and economic factors affecting the suitability of an area for waste siting. In recent decades, GIS and Remote Sensing techniques have proven essential for identifying suitable sites for solid waste disposal due to their ability to manage large volumes of both spatial and non-spatial data.

The process of selecting a landfill site using geospatial technology like GIS is itself a technological advancement in waste management. It improves the final disposal of the components of Municipal Solid Waste. Secondly, proper selection reduces the travel cost, sound management of waste, and the overall environmental sanitation condition for residents [46]. There are no available records indicating a rigorous selection process for the current site. A far distant area, where land could be assessed and accessibility possible was selected. However, over time, the adjoining communities protested the environmental and health conditions as a result of the operationalisation of the site.

The present study identified suitable locations for landfill siting in the Bolgatanga Municipality of Ghana by conducting multi-criteria evaluation using GIS techniques and an overlay analysis process which involved overlaying various layers of information in a GIS domain utilizing their overall weights of importance from the pairwise matrix and the last composite suitability map acquired. The various criteria and constraints considered in the study were the distance from rivers and streams, proximity to roads, distance from town, slope gradient, and soil type.

The results showed the various ranks assigned to different areas within the study area, with the regions closest to rivers and/or streams being assigned the lowest rank of 1 signifying their unsuitability for siting a landfill. Regions between 163.87 *m* and 327.74 *m* away from streams and rivers were assigned a rank of 2 to show they are moderately suitable for landfill siting, while farther areas, 327.74–491.6 *m*, and beyond 500 *m*, were considered the most suitable and hence assigned a rank of 3. Likewise, areas that were 664.53 m–996.80 *m* away from the roads were considered the most suitable areas for siting a landfill. Areas 332.27–664.53 away were classified as suitable, ranked 2, while areas that were 0–332.27 *m* away from roads within the study area were ranked 1 to designate as unsuitable.

The study also showed that a slope gradient ranging between 1 and 0.49% was considered not suitable, 0.49%–0.87% slope gradient was considered suitable, while areas with a slope gradient between 0.87% and 2.43% were considered the most suitable areas. Finally, based on the chemical and physical properties of the different soil types in the study area, Luvisol-covered areas were considered the most suitable areas for landfill siting, and the areas covered with gleysol soil type were ranked 5 as the least suitable region for solid waste disposal. A combination of all weighted criteria through a model builder process produced a suitability index map for candidate landfill sites. Overall, four classes of candidate sites were identified based on their suitability rankings, including restricted areas (ranked 0), unsuitable areas (ranked 1), suitable areas (ranked 2), and most suitable areas (ranked 3). The newly selected site has access to a paved road for much of the travel distance and this reduces travel time and travel cost as with the current site. It is also a distance away from rivers and vegetation. However, both are about 3 km within the proximity of rural settlements.

The findings expose the weaknesses in environmental planning in the municipality. Generally, district assembly(s) in Ghana have no comprehensive physical plans to cater for final disposal sites and therefore have resorted to timely locations. Some of the temporal sites belong to individual landowners who over time demand for their land or compensation which the assemblies find it difficult to pay. Most of the assemblies rely on private waste management companies to manage their landfills. This arrangement has received unfavourable complaints from the assembly pointing to ineffectiveness and inefficiencies.

These findings also provide valuable information that could aid in the selection of suitable landfill sites within the Bolgatanga Municipality of Ghana. Therefore, it is recommended that the relevant authorities should prioritize the identified candidate landfill sites for solid waste disposal within the region. The suitability index map produced provides a clear visual representation of the most suitable landfill sites. Therefore, it is also advisable to conduct periodic monitoring and evaluation of these sites to ensure they remain suitable for waste disposal and comply with environmental regulations.

The Environmental Protection Agency Landfill Guidelines [37], clearly outline the conditions for siting a landfill and stipulates a buffer of 500 m away from river bodies. In the present study, a distance of approximately 164 *m* away from water bodies was considered restricted and therefore unsuitable. Similarly, between 164 *m* and 328 *m* away from water bodies was regarded as suitable, while between 328 m–492 *m* away and beyond it was noted as most suitable for siting the solid waste disposal (Table 4; Fig. 6). Landfill sites should have a mandatory separation distance from water bodies depending on the topography, landscape, soil type, and toxicity of the contaminants. This is to reduce and/or avoid potential damage to water quality [47,48]**.** The result was similar to the findings of [49] who also used a 500 *m* buffer for streams but restricted areas above 1000 *m*.

The selected site (Fig. 6 (B) is far from the existing MSW disposal site located at Sherigu, this indicates how economically and environmentally inappropriate the site is and the need for a better site that is better situated for socio-economic and environmental considerations. It is economically advisable for landfills to be sited closer to points of waste generation and should be easily accessible [45,50]. However, sitting landfills very close or very far from roads comes with other problems including roadblocks and traffic congestion, higher costs of transportation, and health problems [9]. Although modern science, computing, availability of spatial datasets, and diverse expertise may conveniently and accurately help to identify the optimal locations for municipal solid waste, the challenges with these sites are the management levels which may compromise the exigencies for the selection of those landfill sites and facilities. Overall, we have observed that the application of different methods of AHP Site selection such as AHP & FTOPSIS [46], Fuzzy Analytical Hierarchy [51], and Fuzzy AHP & machine learning algorithms [52] in a GIS produces very optimal locations much suited to both environmental and socio-economic concerns.

The limitation of this work has to do with restricting the analysis to a single district. A proper analysis for the selection of a landfill site must include all neighbouring districts. Moreover, cost components such as the travel cost and eventual cost to the household must be incorporated into such a model [46]. A model of any human endeavour which does not consider the entire spectrum of socio-economic challenges, but only environmental consequences would be limited in its application.

Author contribution statement

Conceived and designed the experiments -Steve Ampofo and Joan S. Issifu.

Performed the experiments; Steve Ampofo & Joan Sanaa Issifu.

Analyzed and interpreted the data- Steve Ampofo, Joan Sana Issifu, Michael Mba Kusibu & Freda Adiali.

Contributed reagents, materials, analysis tools or data- Steve Ampofo, Joan Sana Issifu, Michael Mba Kusibu, Sumaila Mohammed Asaah, Freda Adiali.

Wrote the paper - Steve Ampofo, Joan Sanaa Issifu & Michael Mba Kusibu.

Data availability statement

Data will be made available on request.

Declaration of competing interest

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

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