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Investigation Of Solid Waste Disposal Sites Suitability Using Remote Sensing Data And Geographic Information System In Gombe And Environs North-Eastern Nigeria

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ABSTRACT
This paper aimed at investigating and identifying suitability sites for solid waste disposal in Gombe and its surroundings, Nigeria in order to address the environmental and groundwater contamination problems associated with waste disposal sites. Data acquisition from remote sensing images and topographical map of Gombe as well as ground control points using Global positioning system were used as major sources of information for this study. Six Multi-Criteria Analysis were considered to identify the most suitable sites for solid waste disposal sites. The analytical hierarchy process (AHP) and geographic information system (GIS) were used for identification of suitable solid waste dumping sites. The final output of the waste dumping suitable sites has been extracted using the six parameters, namely distance from the borehole, distance from the road, distance from the river, land use and land cover, slope, and geology. The results reveals that out of sixteen waste dumpsites considered only Ashaka Kwami Road waste dumpsite, Kurba Kwami Road waste dumpsite and Mega Park waste dumpsite were suitable for solid waste disposal site in Gombe and Environs. The land use and land cover bare/open space area of 18.34% was highly suitable, slope of area 35.12% was also suitable for ideal waste disposal site, distance from road network with percentage areas of 9.60% and 17.90% with distance 1,500m and 2000m respectively were considered highly suitable. Buffer distance from river of 1,500 m – 2000 m were classified highly suitable for waste disposal sites while distance of less than 500 m with percentage area of 80.28% was considered unsuitable. The finding also indicated high suitability index of 4.14 and low suitability index of 1.54 which the southern part of the metropolis was not good for waste dumpsites due the settlement and buffer distance from the boreholes area and the best areas for waste disposal sites are found at the northern part of the study area where there was less development or human activities. It was recommended that when selecting appropriate locations for dumpsites, the urban planners and legislators should utilise this study for proper waste management infrastructure that is less hazardous.
Keywords: Disposal site, Remote Sensing, GIS, Suitability, Multi-Criteria

1.0 INTRODUCTION
The choice of a solid disposal location is essential component of the waste management, which requires careful consideration to prevent environmental hazard to humans and other living things, health problems,

and consuming wealth worldwide in developed and developing nations (Bhowmick, 2024). The majority of African cities, particularly those in impoverished areas, use open dumping for solid waste disposal. In a nation like Nigeria with limited resources and fast growing urbanization, choosing suitable locations and controlling solid waste disposal are more challenging. The main environmental issue endangering human existence is the indiscriminate disposal of toxic waste and effluent due to the rapid increase in consumption. Industrial debris, agricultural waste, sewage treatment materials, trash, dead animals, and things from human activity that are not beneficial to human existence and occasionally pose a health risk are all considered as solid waste (Majibar, 2008).

Dumping sites in Nigeria don't appear to be strategically permitted because they are usually open disposal sites without sanitary landfills, near to communities, not far enough from the town center (Emmanuel, 2017). Gombe State had a sanitary department called Gombe State Environmental Protection Agency (GOMSEPA) and cleaners were hired to maintain a waste-free and clean metropolitan region. Despite these efforts, people still carelessly disposes waste, which have impact on natural air, water, and land (Kwarki, 2021). Poorly built waste disposal facilities can contaminate soil and groundwater systems, according to studies on the implications of not design garbage dumps on soil and shallow aquifers (Olukanni, Olujide, & Kehinde, 2017).

A useful instrument for acquiring, storing, manipulating, verifying, and analysing data that is spatially linked to the earth is geographic information system, a computerized information device (Dararo, 2025). GIS uses maps and plans to handle both location and attribute data. The flexibility of geographic information systems to take care of massive amounts of spatial information from several means makes it perfect for this type of evaluation study. Appropriate disposal sites have rapidly grown into a major issue in metropolitan areas due to population development and the resulting increase in trash production. For instance, since Gombe became the state capital in 1996, Gombe's population, infrastructure, business, and industry have all increased, which has led to an increase in garbage production. Refuse burning has been the most popular method of disposing of waste, yet it clearly poses health risks to the environment. Conversely, Remote Sensing (RS) is a sophisticated method that is highly useful for in-depth location investigation. This method aids in determining how abrupt changes affect the pattern of land usage. Additionally, it facilitates the visualization of recent on-site data, which is useful when assessing the suitability of land use (Berisa & Birhanu, 2015).

In order to identify potential ways to mitigate the effects of waste dumpsites caused by pollution, this study examined existing disposal sites in Gombe and surrounding areas using remote sensing data, and GIS. It was achieved through considering some multi-criteria analysis, including; distance from water sources, Geology, land use and land cover slope and distance from the road network as in Wanore, (2023).

2.0 Statement of the Problem

According to National Population Commission of Nigeria and National Bureau of Statistics(web); Gombe State has a population of about 3,960,100 million people and land cover of about 16,639 square km of area, 238.0/square km population density and 3.3% annual population changes from 2006-2022. Gombe is fast growing in terms of population and development as a result of security challenges in the North-east, many people are migrating to Gombe for safety as such solid waste too is at increasing level as the population increases due to human activities. It was observed by the researcher that less works have been done using GIS, and RS to investigate various dumpsites at Gombe to ascertain whether the sites are suitable or not. Beauty of environment depends on how hygienic it is; this is because a clean environment prevents infections and illnesses from endangering animals and people's lives living in the environment. Therefore, every one of Nigeria's urban areas struggle with the issue of disposal sites (Doka, 2023). To prevent unanticipated effects of the deterioration of urban health, it is crucial to designate an appropriate location for the dumpsites in Gombe and its environs.

3.0 Study Area

This study was carried out in Gombe Metropolis, which is situated in north-eastern Nigeria. The state capital, Gombe, is a fast-growing metropolis with rising urbanization, population expansion, and garbage

production issues. The city has a tropical continental climate with distinct seasons and located within the Sudan Savannah biological zone (Mbaya, 2017). The stability of garbage disposal sites and environmental vulnerability are greatly impacted by the yearly rainfall pattern and seasonal surface runoff. Gombe State, Nigeria, also referred to as Jewel State, is the research area. Gombe State is situated in north-eastern Nigeria between latitudes 10º 15' and 10º 19' N and longitudes 11º 07' to 11º 15' E (Mbaya,2017). Gombe State, which is situated in Northeast, is shown on the map of Nigeria in Figure 1. Gombe town served as an administrative and business hub of Gombe State, which established in 1996 from Bauchi State.

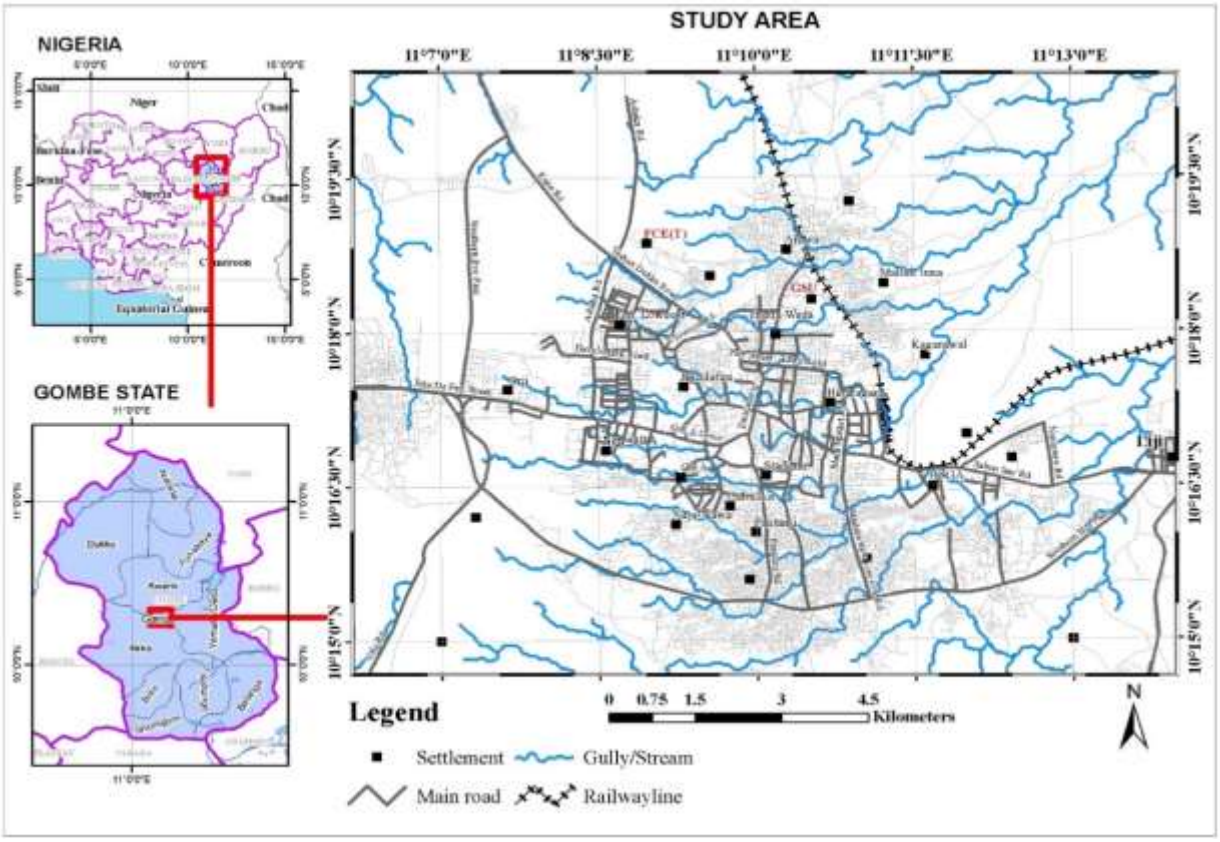

Figure 1: Map of the study Area Gombe, Nigeria.

4.0 Methods

To evaluate current solid waste disposal sites and identify appropriate sites for future waste disposal areas in Gombe and the surrounding area, this study uses an integrated Remote Sensing (RS), Geographic Information System (GIS), and Analytical Hierarchy Process (AHP) approach (Bhowmick, 2024). The methodology was structured to ensure scientific rigor, spatial accuracy, and objective decision making through a multi-criteria evaluation framework. The combination of geospatial techniques and AHP provides a systematic means of incorporating environmental, geological, hydrological, and socio-economic factors into landfill site suitability assessment. The research design follows a spatial multi-criteria decision analysis (MCDA) framework. First, relevant spatial datasets were acquired, Digital Elevation Model (DEM) was performed to get the geological maps, land use/land cover maps, road networks, river/stream networks, borehole locations, and slope after coordinates obtained for the existing dumpsite through GPS field survey.

Landsat satellite imagery was performed at 30 m spatial resolution, dated 24/05/2025 and used for Land Use and Land Cover classification and visual interpretation of surface features. The imagery provided spectral information necessary for distinguishing built-up areas, vegetation, agricultural lands, bare surfaces, and rock outcrops. These topographic variables are essential for evaluating waste dumpsite,

drainage conditions, erosion potential, runoff behaviour, and environmental suitability for landfill sitting. To ensure compatibility for weighted overlay calculation and thematic layers were subjected to raster format and to a common spatial resolution of 30 m for reclassification into a uniform suitability scale (typically 1–5). This standardization ensured that all criteria contributed proportionally according to their AHP derived weights during the final suitability modelling. Through these pre-processing procedures, all datasets were transformed into consistent, analysable thematic layers suitable for integration into AHP-based multi criteria decision analysis framework.

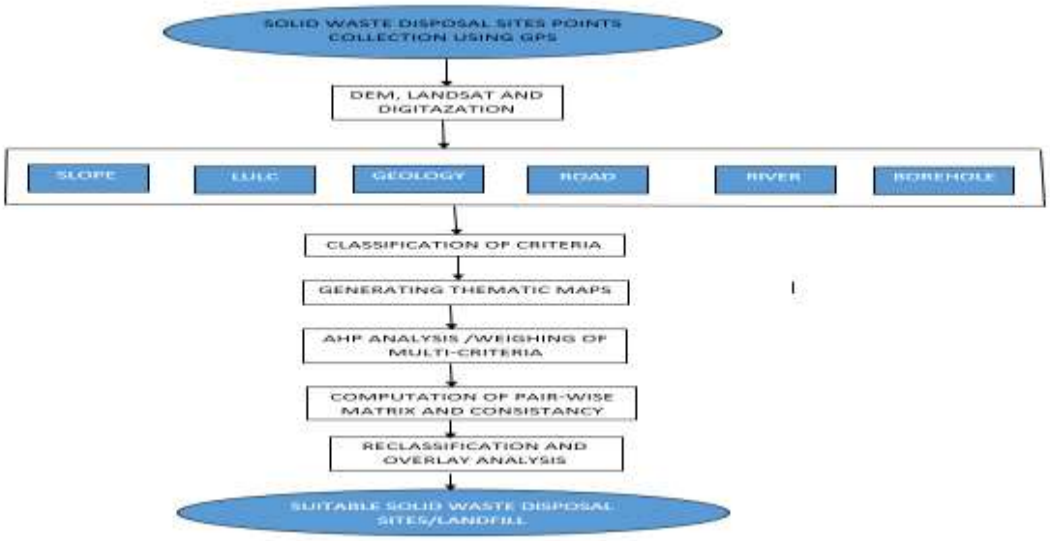

Figure 2: Flow chart Methodology

5.0 Sample and Sampling Techniques

Sixteen (16) waste dumpsites in Gombe and its environs were selected and six criteria were used as samples to investigate the existing solid waste disposal sites using remote sensing data and GIS in areas where there are industries, hospitals, factories, schools, market and more densely populated environments were sampled for this study.

6.0 RESULTS AND DISCUSSION

Sixteen waste dumpsites and 5 grave yards were considered as two categories of solid waste disposal sites in this study. The map of existing waste disposal sites of Gombe and environs is presented in figure 3. To get information from existing waste disposal sites DEM was acquired and derived elevation and slope. These topographic variables are essential for evaluating drainage conditions, erosion potential, runoff behaviour, and environmental suitability for landfill sitting.

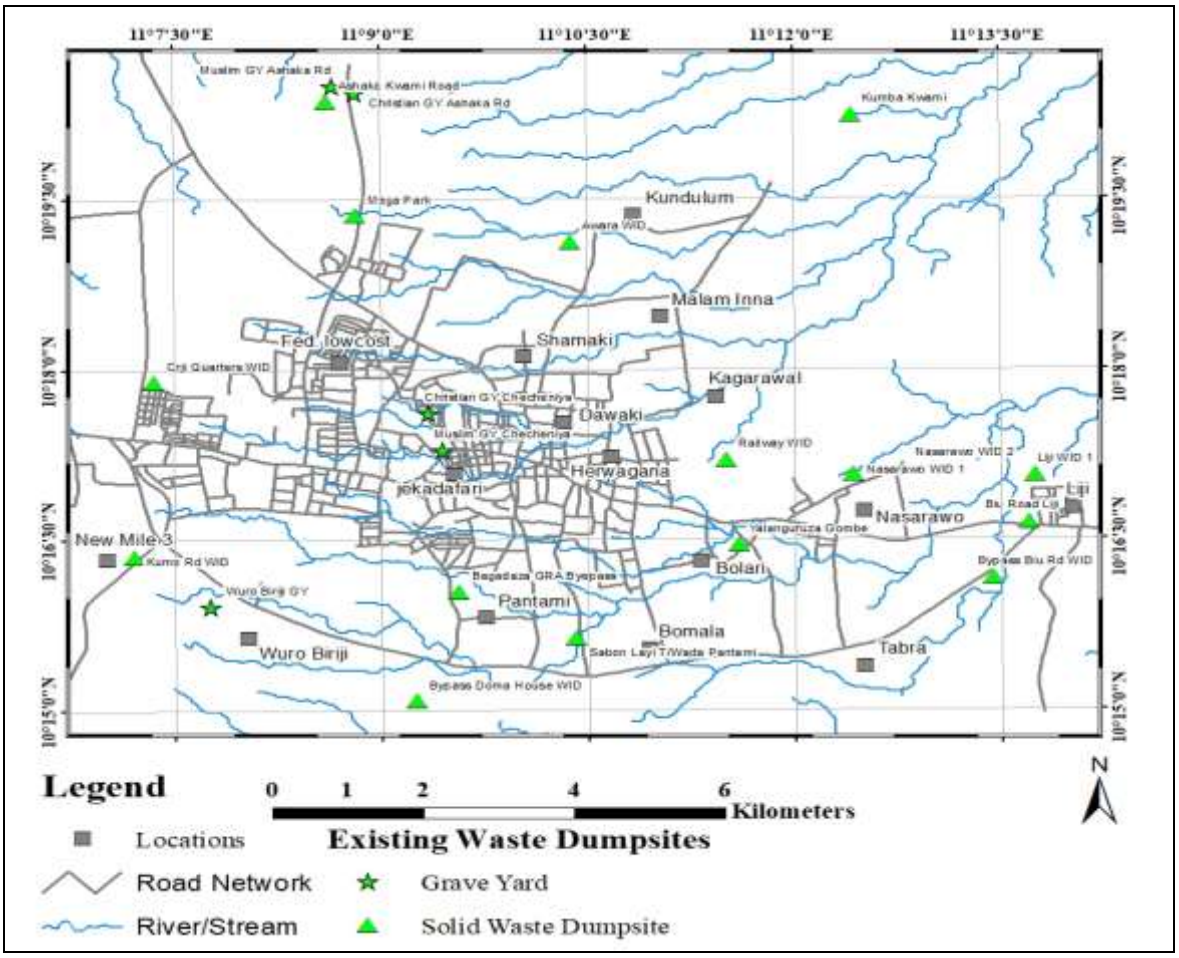

Figure 3: Map of Existing Solid Waste Dumpsites of Gombe and Environs

Table 1: Boreholes Distance Classification based on Area, Weight, Suitability and Rationale

Borehole Distance (m)	**Area(km^2)**	**Area %**	**Weight**	**Level of Suitability**	**Rationale**
<500	10.37	15.30	1	Unsuitable	High contamination risk
1000	9.43	13.90	2	Less Suitable	High risk
1500	7.02	10.35	3	Moderately Suitable	Moderate risk
2000	5.61	8.27	4	Suitable	Low contamination risk
>2000	35.39	52.18	5	Highly Suitable	Safe from contamination
	67.82	**100.00**			

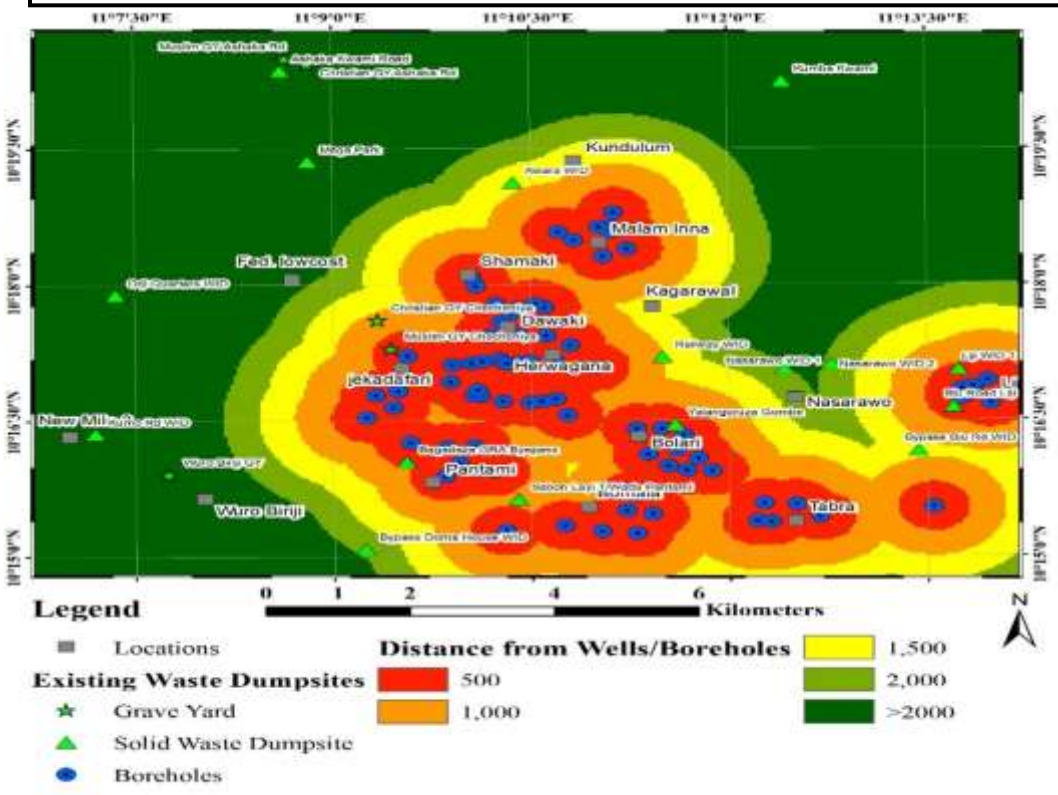

Figure 4: Distance of Solid Waste Dumpsites from Borehole

Table 2: Distance from Road Classification based on Area, Weight, Suitability and Rationale

Distance to Road(m)	Area(km^2)	Area %	Weight	Suitability	Rationale
<500	36.92	54.40	1	Unsuitable	High pollution, nuisance
1000	12.22	18.10	2	Less Suitable	Less pollution and odour
1500	6.52	9.60	3	Moderate Suitable	Good accessibility
>2000	12.16	17.90	4	Highly Suitable	Safe risk
Total	**67.82**	**100.00**			

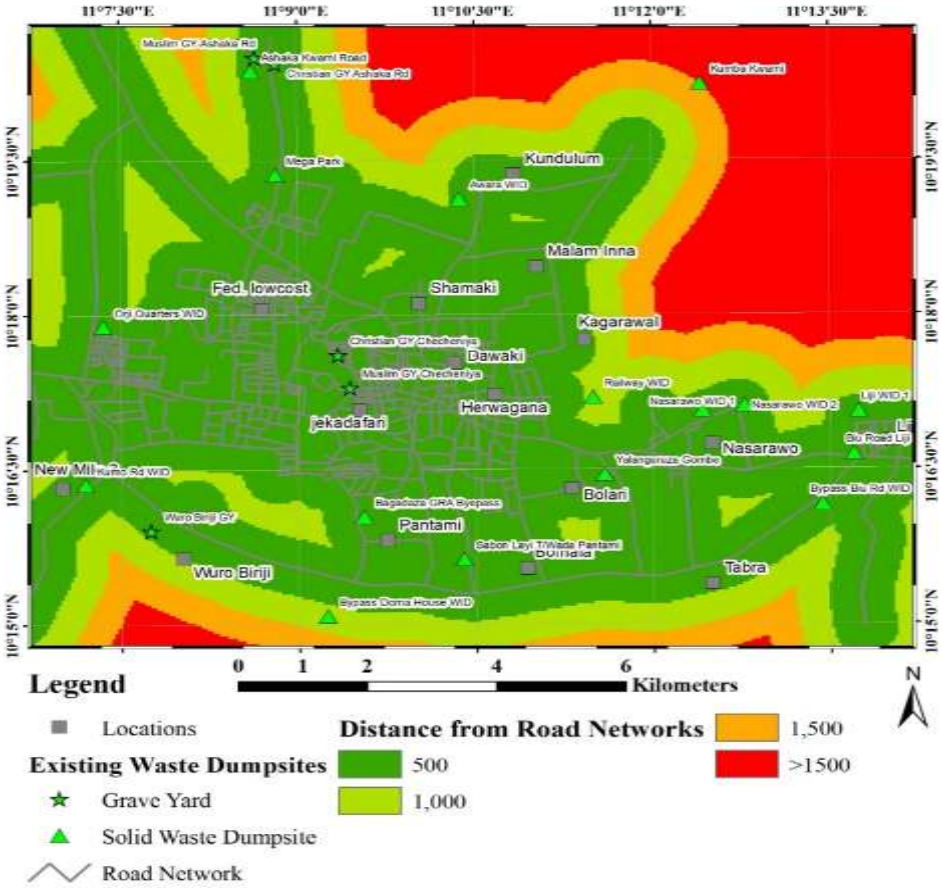

Figure 5: Distance of Solid Waste Dumpsites from Road Network

Table 3: Distance from River Classification based on Area, Weight, Suitability and Rationale

Distance to River(m)	Area(km^2)	Area %	Weight	Suitability	Rationale
<500	54.45	80.28	1	Unsuitable	Leachate-surface water not safe
1000	11.72	17.28	2	Less Suitable	Low risk
1500	1.55	2.28	3	Moderate	Moderate risk
>2000	0.11	0.16	4	Highly Suitable	Surface water protected
Total	**67.82**	**100.00**			

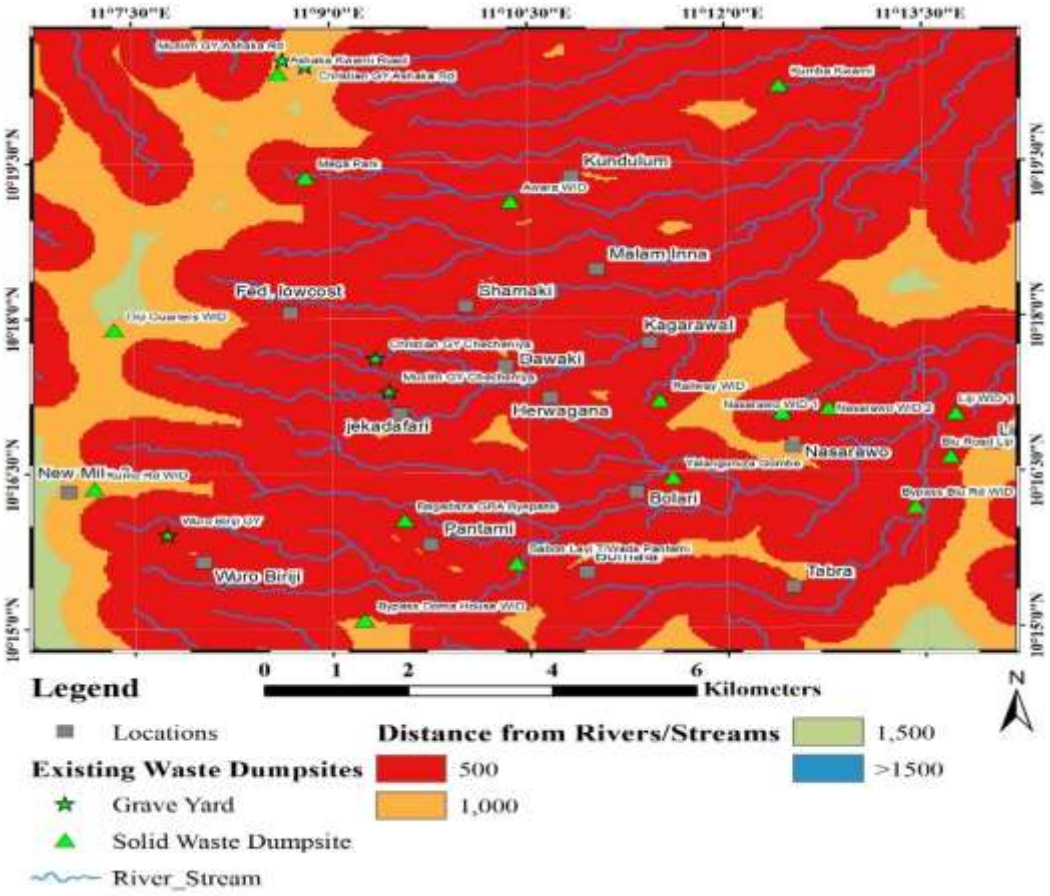

Figure 6: Distance of Solid Waste Dumpsites from River/Stream

Table 4: LULC Classification based on Area, Weight, Suitability and Rationale

LULC	**Area(km^2)**	**Area %**	**Weigh**	**Suitability**	**Rationale**
Vegetation/Grassland	4.88	7.60	3	Moderately Suitable	Environmental impact
Agricultural Land	17.88	27.80	2	Less Suitable	Food security concern
Bare/Open space	11.80	18.34	5	Highly Suitable	Minimal land use conflict
Built up area	26.59	41.40	1	Not Suitable	Public health risk
Rock outcrop	3.12	4.86	4	Suitable	May have fracturing
Total	**64.26**	**100.00**			

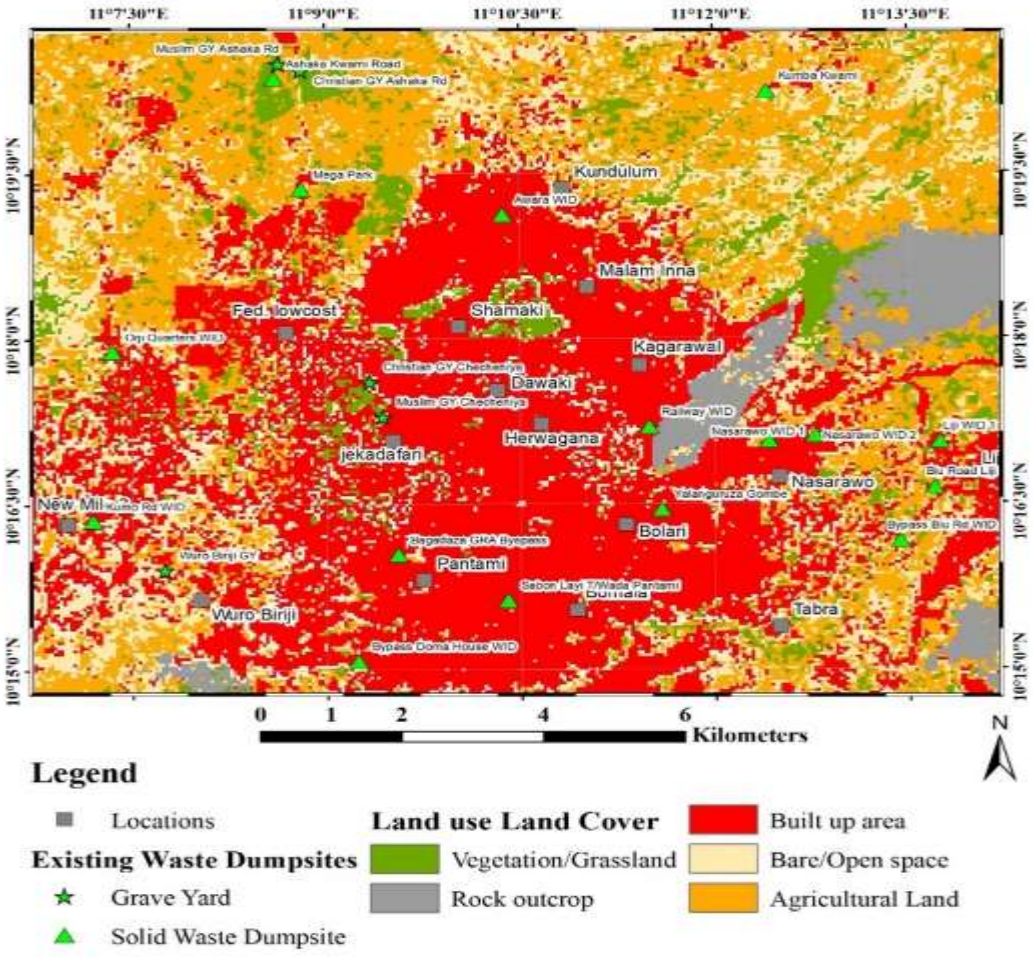

Figure 7: LULC Distance from Solid Waste Dumpsites

Table 5: Geology Classification based on Area, Weight, Suitability and Rationale

Geologic formation	Area(km^2)	Area %	Weight	Suitability	Rationale
Keri-Keri	22.71	33.50	2	Less Suitable	Higher permeability
Gombe sandstone	17.44	25.72	2	Less suitable	Higher permeability
Pindiga	16.17	23.85	3	Moderately Suitable	Moderate permeability
Yolde	5.98	8.82	3	Moderately Suitable	Moderate permeability
Bima	3.37	4.97	4	Suitable	low permeability
Basement Complex	2.13	3.14	5	Highly Suitable	Lower permeability
Total	**67.80**	**100.00**			

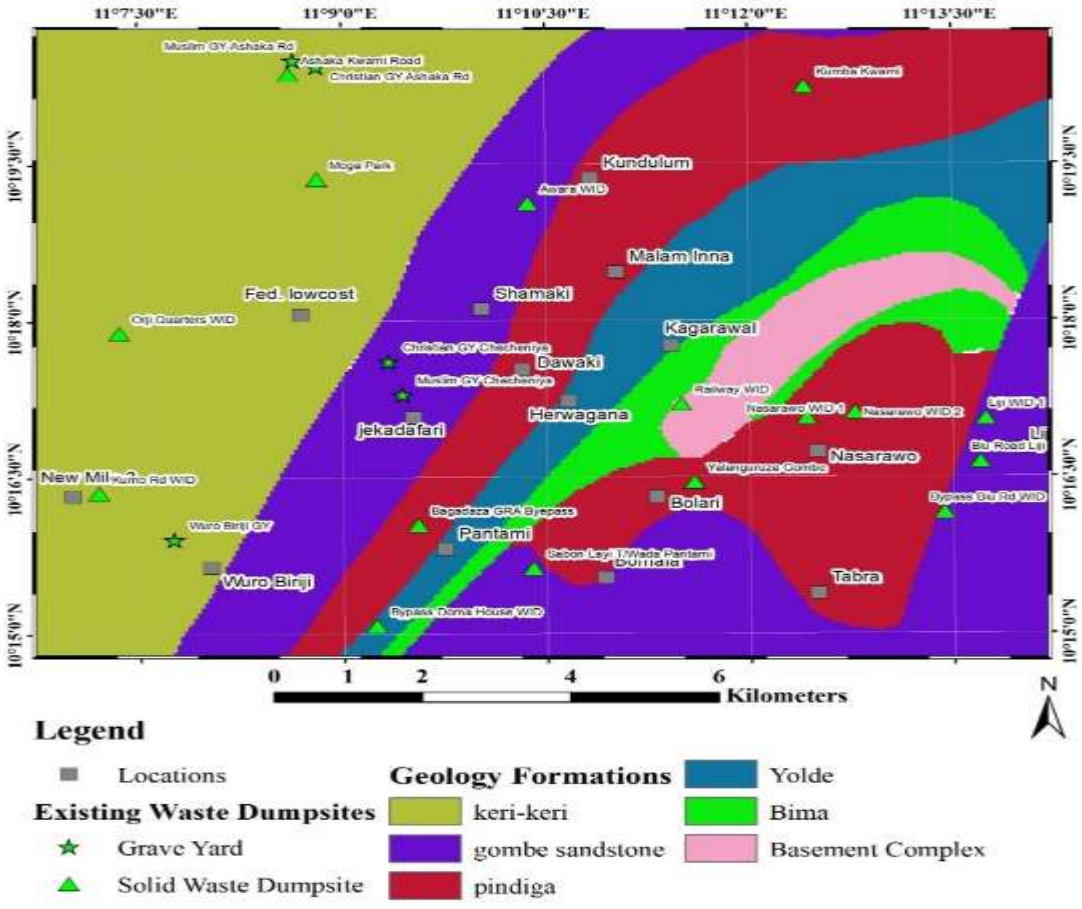

Figure 8: Geology Formation from Waste Dumpsites

Table 6: Slope Classification based on Area, Weight, Suitability and Rationale

Slope (in Degree)	Area(km^2)	Area %	Weigh	Level of Suitability	Rationale
Gently sloping (2-5^0)	23.81	35.12	5	Highly Suitable	Ideal waste dump
moderate sloping (5-10^0)	19.34	28.52	4	Suitable	Good for operation
strongly sloping (10-15^0)	13.39	19.75	2	less Suitable	Erosion risk
Steep (>15^0)	11.26	16.61	1	Unsuitable	High erosion risk
Total	**67.81**	**100.00**			

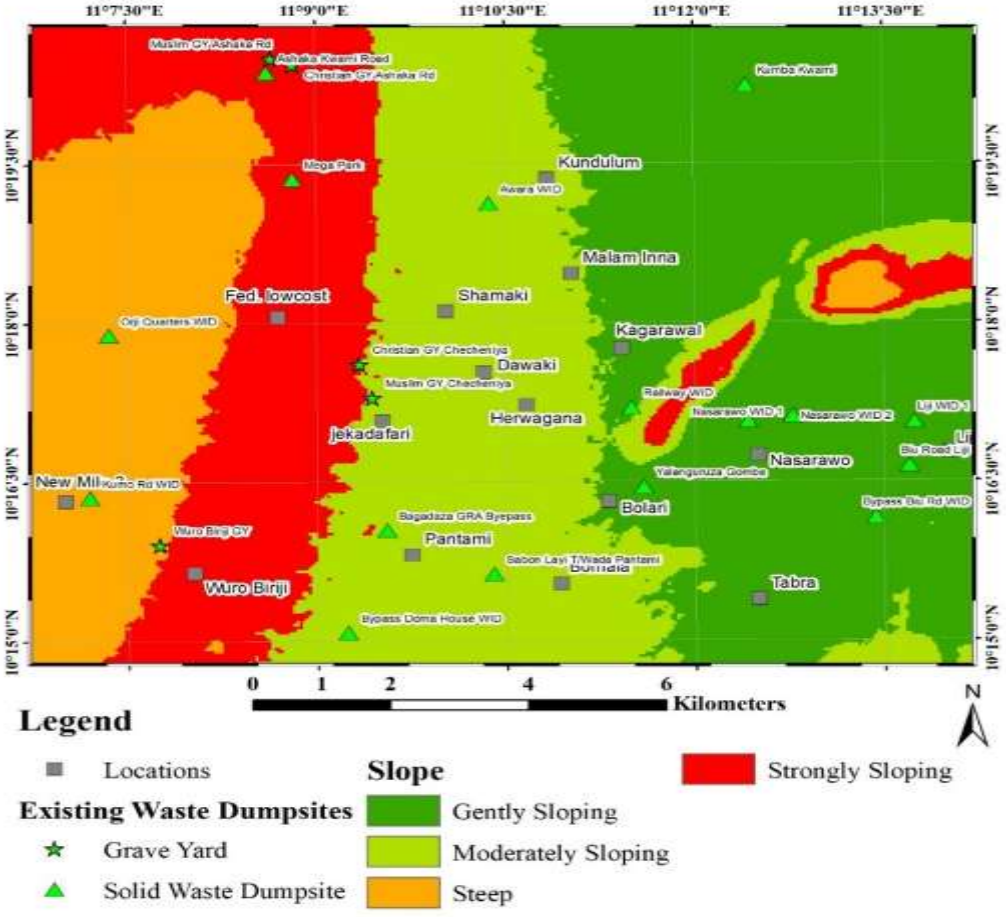

Figure 9: Slope of Waste Dumpsites in Gombe and Environs

Table 7: Decision Matrix/Pairwise Comparison Between Criteria

Criteria	Borehole	River Distance	Geology	LULC	Slope	Road Distance
Borehole	1	2	3	4	4	5
River Distance	0.50	1	2	3	3	4
Geology	0.33	0.50	1	2	2	3
LULC	0.25	0.33	0.50	1	2	2
Slope	0.25	0.33	0.50	0.50	1	2
Road Distance	0.20	0.25	0.33	0.50	0.50	1

Principal Eigen value λ = 6.126, Consistency Ratio CR = 0.02. Note: Value 1 indicate row criterion is more important than column criterion.

Boreholes Distance: Waste dumping generated from large-scale pollution causes water pollution. Waste dumping also causes filing up and deterioration of wells/boreholes. Hence, locating dumping grounds at a considerable distance from water sources is advisable. (Alavi et al., 2013; Colvero et al., 2018). This research advocates maintaining a minimum buffer zone of 1000-2000 m around all types of natural or artificial water bodies. The area 67.82km^2 considered; distance less than 500 m (15.30%) was considered unsuitable due to the high contamination risk and pollution, distance of 1000 m (13.90%) was less suitable because of less pollution risk, distance of 1500 m (10.35%) was moderately suitable for moderate risk, distance of 2000 m (8.27%) is considered suitable for waste disposal due to low contamination risk and distance greater than 2000 m (52.18%) was considered highly suitable for waste disposal as in Dararo, et al., 2025. Fig. 4 and Tab. 1.

Distance from the Road Network: The consideration of distance from road network is consistently regarded as a significant economic determinant in Waste dumping site selection (Hazarika and Saikia, 2020). Waste disposal plants mustn't be situated close to roadsides. However, placing landfill sites at considerable distances from road is not cost-effective due to the necessity of constructing new roads and incurring additional waste collection and transportation expenses. A minimum distance of 100 m is typically prescribed for the allocation between waste dumping and roadways (Saketa et al., 2023). This study developed four buffers adjacent to roadways, categorized in Fig. 5 and Tab. 2. The area 67.82 km^2 considered; distance less than 500m (54.40%) was considered unsuitable due to the high pollution and nuisance, distance of 1000m (18.10%) was less suitable because of less pollution and odor, distance of 1500m (9.60%) was moderately suitable for good accessibility and distance greater than 2000 m (17.90) were considered highly suitable for waste disposal which correspond with Dararo, et al, 2025 results.

Distance from the River/Stram: Disposing Waste on or near any water surface, such as a river or stream is strictly illegal according to the guidelines set by the Central Pollution Control Board in 2008 (Bhawan and Nagar, 2008). Dumping sites close to streams and rivers are typically circumvented to mitigate the susceptibility to surface water pollution resulting from contamination. Similarly, waste dumpsites must be situated at a minimum distance of 100 m from rivers (Roy et al, 2022). This study has developed four buffers, namely < 500 m, 1000 m, 1500 m, and > 2000 m (Fig. 6 and Tab. 3). The buffer of < 500 m with percentage area of 80.28% was classified as unsuitable for waste dumping due to leachate surface water not safe (Basha et al., 2023), while the buffer of > 2000 m with percentage area of 0.16% was classified as highly acceptable for waste dumping because surface water is protected which was similar to (Basha et al.,2023 and Dararo et al., 2025).

Land use/Land cover: The land-use and land cover types significantly influenced the suitability of locations for locating dumpsite (Saketa et al., 2023). In this study, 5 LULC classes have been identified: Vegetation/Grassland, agricultural land, bare/open space, built-up area, and rock outcrop are restricted for waste dumping, and fallow land is suitable for waste dumping (Fig. 7). It is important to note that some part of agricultural land is now converted into fallow due to the rapid development of the region and the

economy has been shifting from primary to secondary. It is advisable to select land that was occupied by bare and grass lands. The area under each land use and cover is shown in Table 4. Out of the total area of 64.26 km^2considered; Vegetation/grassland with 7.60% was considered moderately suitable due to environmental impact, agricultural land 27.80% was less suitable because of food security concern, bare/ open space 18.34% was considered highly suitable for minimal land use conflict and health risk, build up areas 41.40% was not suitable due to public health and rock outcrop 4.86% was suitable for fracturing purposes as in (Basha et al., 2023; Bhowmick et al., 2024, and Oluwanimifise & Anyaeche, 2025).

Geology: Geology formation also very important in waste dumpsite settings. Six formation were considered which covered area of 67.82 km^2 as in Fig. 8. Ker-keri formation with area 22.71 km^2 (33.50%) and, Gombe sandstone area 17.44 km^2 (25.72%) were classified less suitable due to higher permeability, similarly, Pindiga area of 16.17 km^2 (23.85%) and Yolde area 5.98 km^2 (8.85%) were moderately suitable because of moderate permeability, Bima 3.37 km^2 (4.97%) was suitable due to low permeability, and Basement complex area 2.13 km^2 (3.14%) was classified as highly suitable for solid waste disposal site due to Lower permeability which was the same in Olanibi & Emmanuel, 2022. Consider Tab.5.

Slope: The steepness of the slope is an essential consideration when siting a waste dumping site. Different factors are to be considered such as soil water content, the erosion, and the groundwater pollution. Steeper slopes would be difficult to build and maintain, but to flat of a slope would also have an impact on runoff drainage according to (Browne et al., 2014). Steep slope also necessitates more expensive excavation methods and may present erosion issues (Memarbashi et al., 2017), while runoff drainage might be affected by an excessively flat surface (Nas et al., 2010). It has been proposed that landfill sites should be built on terrain with slopes between 0 and 17 percent rise (Basha et al., 2023). The area considered was 6.81km^2 (Fig. 9 and Tab. 6) gently sloping 2^0-5^0 (35.12%) was highly suitable for ideal waste dumpsite, moderately sloping 5^0- 10^0 (28.52%) was suitable and good for operation, strongly sloping 10^0-15^0 (19.75%) was less suitable due erosion risk and steepness, slope greater than 15^0 (16.61%) was unsuitable because of erosion risk which coincided with (Basha et al., 2023).

From table 7. The Analytic Hierarchy Process(AHP) follow a well-defined process involving setting up a pairwise comparison matrix to determine the relative importance of each layer, to also calculate the weighted normalized matrix and determination of consistency ratio by dividing the consistency index by the random index. To calculate the consistency ratio and eigenvalue of the matrix the following formulae were used; The principal eigenvalue (λmax) was calculated to be 6.126 and the determined Consistency Index (CI) was 0.02 which is within the accepted value by using the following equations;

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

The Consistency Ratio (CR) was then computed as:

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

Where:

n= number of criteria (6 in this case)

RI = random index corresponding to matrix size

A CR value less than 0.1 was considered acceptable, indicating logical consistency in the pairwise judgments. Also

$$SuitabilityIndex = \sum(W_i \times X_i)$$

Where:

W_i= weight of criterion i

X_i= standardized suitability score of criterion i

Table 8: Preference Scale of Pairwise Comparison Matrix

Scale	Judgement	Explanation
1	Equal importance	Two activities contribute equally to the object
2	Moderate importance over another	Experience and judgment slightly favour one activity over another
3	Essential or strong importance	Experience and judgment slightly favour one activity over another
4	Very strong or demonstrated importance	Strongly favoured, and its dominance is demonstrated in practice
5	The absolute importance	The highest possible order of affirmation

7.0 Suitability of Final Solid Waste Disposal Zones

Out of the sixteen existing waste dumpsite not all have satisfied every requirement. Therefore, the optimum sites with the least detrimental impact on both human, water and environment is considered as suitable for solid waste disposal site. The location that has least negative effects on environmental factors satisfied the requirements for ideal solid waste dumpsiteby using GIS. According to the final suitability map analyses, only Ashaka Kwami Road waste dumpsite, Mega waste dumpsite, and Kurba Kwami Road waste dumpsite were satisfied for ideal solid waste dumpsite in Gombe and its environs. Consider suitability index map figure 10.

8.0 CONCLUSION

In developing nations like Nigeria, suitable site selection for solid waste disposal is one among the most current issues that need to be address for proper waste management. Remote sensing, GIS tools and AHP analysis methods play a significant role within the disposal site selection modelling. This study has selected 6 thematic criteria including; distance from Boreholes, distance from rivers/streams, geology, land use/land cover, slope and distance from road networks in step with the study area conditions and availability of the relevant data. Waste are the inevitable product of daily human activities posting major challenges to humanity when improper places are used for solid waste dumpsites and poor management especially in developing city like Gombe.

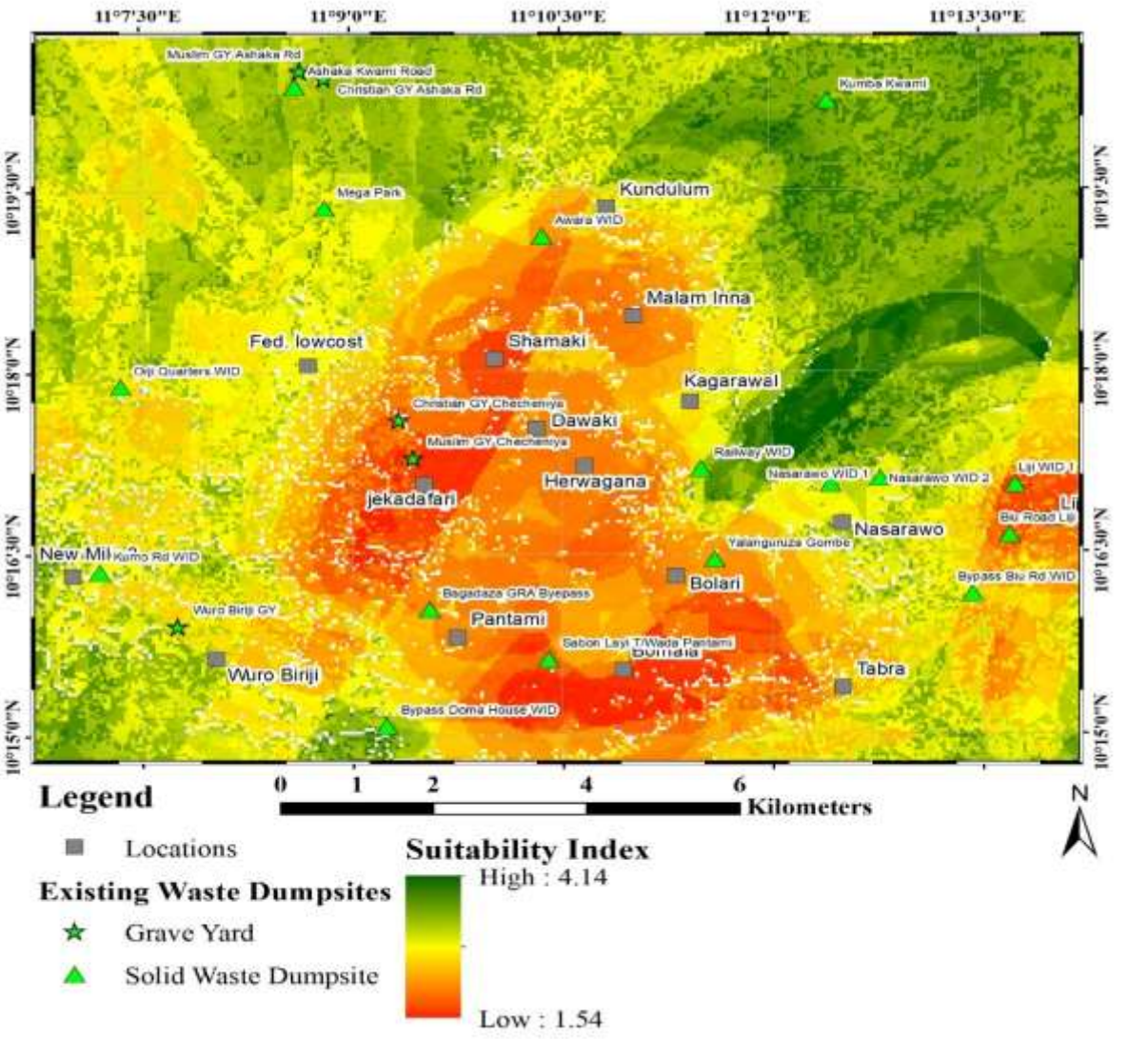

Figure 10: Suitability index Map of Solid Waste Disposal Sites in Gombe and Environs

The sixteen waste dumpsites considered; only three meet the requirement for suitable solid waste disposal sites, the remaining thirteen were unsuitable. Since this empirical study was limited to solid waste disposal sites in Gombe and its environs, it is necessary to include more criteria with the view to increasing accuracy of the investigation. Moreover, there is a need to integrate this investigation with 2-D electrical resistivity methods to ascertain the level of leachate plums in relation to groundwater and soil contamination around solid waste dumpsites in Gombe and its surroundings. The current results may provide information to the administrators and urban planners of Gombe town to locate an appropriate site for solid waste disposal and assist the state government in resolving solid waste administration issues.

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