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ASSESSMENT OF THE IMPACTS OF CLIMATE CHANGE IN SITE SELECTION FOR SOLID WASTE DISPOSAL WITHIN IBADAN METROPOLIS

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ABSTRACT

The impact of climate change as a global issue significantly affects multiple aspects of human life and the environment. One area that has been significantly affected by climate change is the management of solid waste disposal. This research investigates the impact of climate change in selecting land suitable for solid waste disposal sites in the Ibadan metropolis. As cities grow and climate-related hazards increase, there is a need to reevaluate the process of selecting waste disposal sites. The study identifies the climatic conditions that impact solid waste disposal sites from the reviewed literature and also identifies changes in climatic conditions that impact sites suitable for solid waste disposal, and this is achieved through historical meteorological data. A site suitability assessment was carried out at selected intervals based on climate change and other criteria such as Elevation, slope, proximity to water bodies, proximity to road networks, and land use/land cover maps. Multi-criteria decision-making techniques adopted are the analytical hierarchy process and reclassification. Results indicate significant urban expansion, with increased built-up areas encroaching on potential waste disposal sites. Temperature trends show fluctuating levels, starting at 298 K in 1979 and increasing to 299.5 K in 2023. There have been periods of decline, but significant increases since 2007. Precipitation trends show fluctuating levels from 0.00431mm in 1979, 0.00544mm in 2007 with a slight decrease over the years, and 0.00429mm in 2023. The outcome of the study shows that the study area covering a total extent of ~308,000 hectares, 23.52%, 22.93%, 20.05%, 17%, and 16.49% for 1979, 2007, 2013, 2020, and 2023, respectively, are land suitable for siting solid waste disposal sites in Ibadan metropolis.

Keyword: *Climate change, Precipitation, Temperature, AHP, Solid waste disposal.*

1.0 Introduction

Climate refers to the long-term average weather patterns and conditions observed in a particular region or on Earth as a whole (Nabegu, 2012). It encompasses various atmospheric factors, such as temperature, precipitation, humidity, wind, and atmospheric pressure, as well as their variations and extremes over extended periods typically spanning decades to centuries (Michael and Richard, 2020). The climate is relatively stable and evolves slowly over time, showing trends and variations across longer timeframes. It is influenced by complex interactions between the atmosphere, oceans, land, and ice, as well as external factors, such as solar radiation and volcanic activity (IPCC, 2021).

Climate change refers to the long-term shift in the Earth's climate, typically marked by variations in temperature, precipitation patterns, and weather events (Michael and Richard, 2020). It is largely driven by human actions such as burning fossil fuels, deforestation, and industrial activities that release greenhouse gases (GHGs) into the atmosphere (Nabegu, 2012). Richard (2020) stated that these GHGs trap heat from the sun, causing global warming. Greenhouse gases are atmospheric gases that absorb energy slowly or prevent heat from escaping into space. They function like a blanket, warming the Earth. This process, known as the greenhouse effect, is natural and vital for sustaining life by trapping heat to maintain a comfortable temperature on Earth. However, the recent increase in GHG concentrations, driven by human activities, is intensifying this heat-trapping effect, leading to global warming and harmful consequences for human health and well-being. (Ajibade *et al*., 2020). GHG emissions stem from various human activities, including burning fossil fuels for energy, deforestation, and waste disposal in landfills (Hopwood and Cohen, 2008).

The effects of climate change are far-reaching and include rising sea levels, more frequent and intense natural disasters, altered weather patterns, biodiversity loss, and adverse impacts on human health, food security, and water resources (Michael and Richard, 2020). Climate change is recognized as one of the most critical environmental challenges of our time, leading to global initiatives aimed at reducing greenhouse gas emissions and mitigating its effects (Ogunlowo *et al.,* 2020).

Solid waste has emerged as a worldwide environmental and health concern in both developing and developed nations (UNEP, 2005; United Nations, 2017). Improper disposal of solid waste can cause contamination of surface and groundwater due to the leaching of waste deposits, contribute to air pollution, and release methane (Visvanathan and Glawe, 2006). Additionally, indiscriminately discarded solid waste creates aesthetic issues and nuisance in human surroundings.

The rapid urbanization and intensifying effects of climate change pose significant challenges to the efficient and sustainable management of solid waste in Ibadan, Oyo State, Nigeria (Jazat *et al*., 2023; Moruff, 2014). As cities grow and climate-related hazards increase, there is an urgent need to reevaluate the process of selecting waste disposal sites. Jazat *et al*. (2023) and Ogundele *et al*. (2018) argue that the existing waste management infrastructure and practices are inadequate in addressing evolving risks such as flooding, erosion, and temperature variations, which could compromise the stability of waste disposal sites and lead to environmental degradation and public health concerns. Thus, there is a critical knowledge gap regarding how climate change impacts should be systematically integrated into site selection analysis to ensure the resilience, safety, and long-term sustainability of waste disposal practices in Ibadan.

By integrating climate change impacts into the site selection process, this study aim to minimize potential health risks and protect the well-being of Ibadan residents. This study evaluates the consequences of climate change on the selection of sites for solid waste disposal in Ibadan, Oyo State, Nigeria. Adewole, *et al*. (2020)

Previous studies have examined the implications of climate change on waste management in Nigeria. Nabegu's (2012) study examines Nigeria's solid waste generation, its characteristics, current management practices, greenhouse gas (GHG) emissions, especially from the solid waste sector, and the implications for climate change. The study shows that, given the current waste generation and management practices, along with future projections, the solid waste sector will significantly contribute to GHG emissions not only in Nigeria but globally. They emphasize the importance of integrating climate change considerations into waste management policies and practices to enhance resilience and sustainability.

However, there remains a research gap regarding the specific impacts of climate change on site selection analysis for solid waste disposal in Ibadan, and the need for climate change adaptation and mitigation strategies in waste management planning was not analysed for the study area. This research aims to fill that gap by conducting a comprehensive study to understand the unique challenges faced by Ibadan in the context of climate change and to identify effective strategies for enhancing the climate resilience of waste management practices in the city.

1.1 Study Area

The study area is located in the Ibadan district of Oyo State, Nigeria. It spans a latitude range of 7°05′00″N to 7°45′00″N and a longitude range of 3°30′00″E to 4°10′00″E.

Ibadan, the capital of Oyo State, is Nigeria’s third most populous city after Lagos and Kano. According to the World Population Review (2021), the city had an estimated population of 3,649,000. The metropolitan area, which includes surrounding local government areas, is projected to have a population between 4 to 6 million, based on demographic models, past growth trends, and satellite-based assessments (Population Stat, 2021; Macro trends, 2021).

The city spans an area of 3,080 square kilometers, making it the largest in Nigeria after Bauchi. Ibadan experiences a tropical wet and dry climate (Köppen climate classification Aw), with a prolonged wet season from March to October and a dry season from November to February. The dry season also brings the typical West African harmattan (Bankole et al., 2023). Ibadan's average annual rainfall is approximately 1,230 millimeters or 48 inches, occurring over about 123 days, with peaks in June and September. The average daily temperature is 26.46°C or 79.63°F, the average minimum is 21.42°C or 70.56°F, and the relative humidity is 74.55% (Bankole et al., 2023). Figure 1 illustrates a map of the study area.

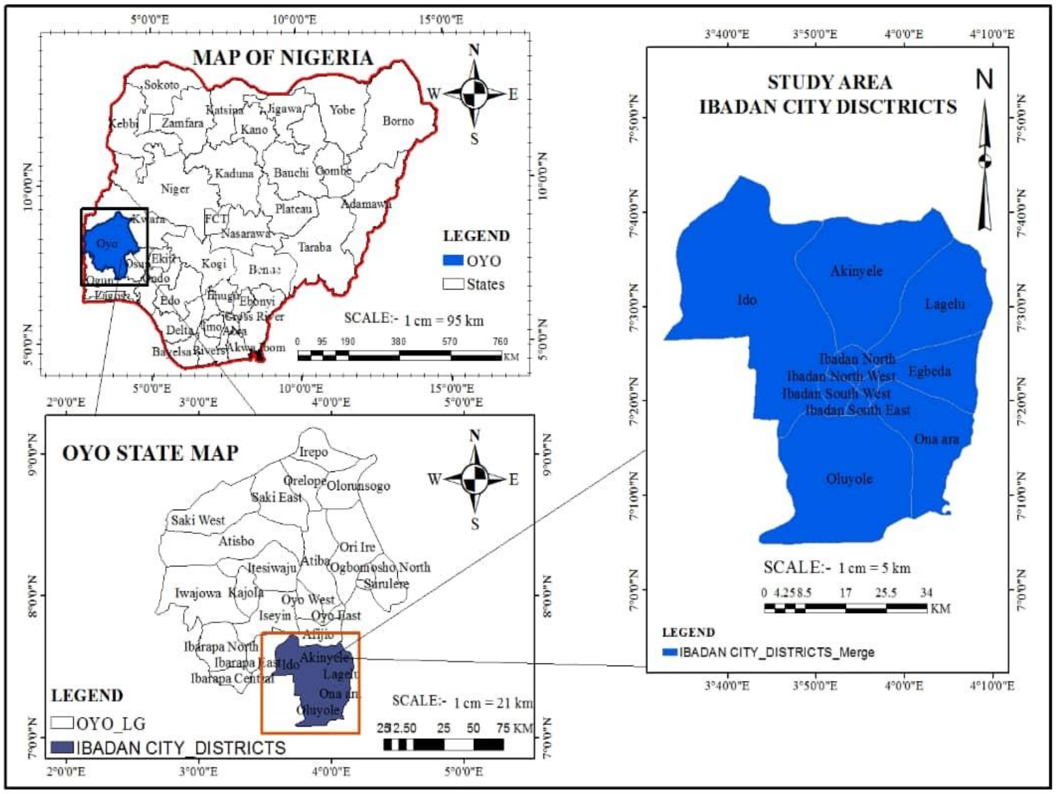

Figure 1: Map showing the study area
Source: Author's Compilation.

2.0 Methods

This study integrates GIS, remote sensing, and climate data analysis to assess the impact of climate change on solid waste disposal site selection in Ibadan. Primary data, including GNSS field surveys, and secondary data, such as Landsat, SRTM, and climate data, are used. Climate change factors like temperature rise, precipitation patterns are analyzed. GIS-based suitability analysis incorporates LULC classification, proximity analysis, and DEM assessments. Multi-Criteria Decision Analysis (MCDA) using the Analytic Hierarchy Process (AHP) assigns weightings to key factors and finally existing waste disposal sites and recommended sites are comparatively evaluated based on climate resilience and other criteria.

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2.1 Data Collection

The summary of the source, data type, and output of the various data collected for this study are presented in Table 1. These datasets were obtained from reliable sources and covered the entire extent of the study area.

Table 1: Details of data required for the research

Datasets	Sources	Resolution/ Format	Year	Uses
Digital Elevation Model (DEM)	National Aeronautical and Space Administration (NASA).Http://www.nasa.gov Shuttle Radar Topography Mission(SRTM)	30 m	2000	DEM, Slope, Drainage
Climatic Data: Temperature, Precipitation.	European Centre for Medium-Range Weather Forecasts (ECMWF). Http://www.ecmwf.int	9Km	1979 - 2023	To identify changes in the climatic conditions of the study area over time.
Landsat Data	United States Geological Survey (USGS)	(Landsat1-3): 79m/Raster (Landsat4-5): 30m/Raster (Landsat8): 30m/Raster	2023	Land-use/land cover(LULC)
High-resolution satellite imagery derived from Google Earth	Digital Globe	1m	2023	High-resolution imagery that serves as the base map for accuracy assessment.
GPS Coordinates	GNSS Field Observation	Vector	2023	Spatial data for accurate positioning of solid waste sites.

2.2 Data Processing

The acquired data were subjected to some processing and analysis, which is discussed in this section: Data Processing involved the methods and procedures used for carrying out this research. The summary of the data processing for this research is based on the objectives, which include:

2.2.1 Changes in climatic conditions that impact sites suitable for solid waste disposal.

The historical meteorological data, precipitation, and temperature data for the study area were collected for the years 1979 to 2023 at different epochs. It was extracted from the European Centre for Medium-Range Weather Forecasts (ECMWF) website. http://www.ecmwf.int, downloaded in Grib format and it is an encoded format that needs to be extracted before it can be used, Phyton programming language was employed for the extraction process, the xarray python library and pandas library were used, the xarray library was used to store the grib file, the pandas library was then used to load the stored grib data for filtering. The filtering method for the pandas dataframe was then used to filter through the dataframe based on the location. The filtered data was converted into a CSV format for readability, further processed and edited in Microsoft Excel, and then imported into ArcMap for interpolation. The historic climate data was used to perform trend analysis to determine the climatic change trend in the study area from 1979 to 2023.

2.2.2 Site suitability assessment at selected intervals based on climate change in the study area

A site suitability assessment was carried out at selected intervals based on climate change and other criteria such as elevation, slope, proximity to water bodies, Land use and land cover, precipitation, and temperature data. The SRTM DEM was used to derive terrain features such as the slope and elevation of the study area. Landsat 4, 7 and 8 imageries were used to derive the Land use/ Land Cover (LULC) classification of the study area. The existing major dump sites in the study area were located by GNSS observation, which is subjected to several analyses.

2.2.2.1 Image Classification

The maximum likelihood classification algorithm was used to classify satellite images based on supervised classification. Because of its low chance of error, the Maximum Likelihood Classification (MLC) parametric algorithm is the most widely used for classifying land cover. It determines the likelihood that every pixel is a member of a specific land cover class. By drawing polygons around the typical areas of each land cover class, training samples are chosen from each satellite image. The area was classified into five (5) different land cover classes, which are water, vegetation, built-up areas, crops and bare ground. The field calculator button was utilized to compute the area of each class depicted on the land use map, using equation 2.1:

$$Area\ of\ each\ Class = \text{Total Number of Pixel per Class} \times \text{Total Resolution of imageries} \ldots\ 2.1$$

2.2.2.2 Slope

The slope of the study area was acquired using the SRTM (DEM) data acquired for the study area. The process involves clipping the desired DEM from the downloaded DEM using the boundary of the study area and the clipping tool of ArcGIS 10.7 software. After the successful running of the clipping, the slope tool present within the spatial analysis tool of ArcGIS toolbox was used to produce the slope map of the study area. The final output was later categorized into three different categories based on the slope value obtained from the analysis.

2.2.2.3 Elevation

The elevation of the study area was derived from SRTM data, and the processing was done in ArcMap 10.7. The SRTM data was imported and preprocessed by clipping it to the study area. The color ramp was applied to symbolize the elevation values visually. This is done by opening the layer properties and selecting a suitable color ramp under the "Symbology" tab. The visualization was enhanced by applying hillshade or slope shading effects to the elevation raster to better represent the terrain features. Other layers, such as water bodies, roads, or administrative boundaries, were overlaid to provide context to the elevation map.

2.2.2.4 Aspect

The Aspect of the area was also acquired from the DEM of the study area. The processing is similar to the processing of the slope variable. Still, it involves using the Aspect tool instead of the Slope tool to get the Aspect representation of the study area. The final result gives the direction of the slope (Aspect) with the study area.

2.2.3 Assessment of the effects of climate change on sites that are suitable for solid waste disposal.

Assessing the effect of climate change was carried out using a combination of GIS and the Analytical Hierarchy Process (AHP), as site suitability is a complex issue that depends on several factors. AHP is used because of the reliability and flexibility of the technique described in past and recent studies, which has gained the approach popularity in allowing a more comprehensive assessment of the impacts and effect of climate change in siting solid suitable sites by assessing the relative importance or preference of selected criteria's by assigning weights to those criteria's. During the planning process and from reviewed literatures, Temperature, Precipitation, Slope, Aspect, Proximity to water bodies, Proximity to road network and Land Use Land Cover are among the factors and criteria that underwent assessment with the help of GIS Software (ArcGIS 10.7) to conduct a geographic study and choose each location suitable for solid waste disposal and this include the following process:

2.2.3.1 Criteria Standardization

The study's criteria were harmonized and placed under a single standard by standardizing them on a scale of 1 to 3. The lowest suitable range of values was given a value of 1, and the maximum suitable range was given a value of 3.

2.2.3.2 Weighted Overlay (Criteria Combination)

The assignment of weights to these criteria is a critical step in the research. These weights are determined based on their relative importance in decision-making (Fülöp 2023). The seven criteria are integrated into the research's GIS platform as raster layers, and each criterion becomes a distinct thematic layer. These thematic layers contain geospatial data corresponding to the characteristic criteria. For instance, the temperature layer includes data on temperature values across the study area, while the land use layer categorizes land into different classes, such as cropland, tree cover, or urban areas. The weighted overlay method is then employed using ArcMap 10.7 to combine these criteria and create a final suitability map. The suitability map represents the composite suitability score for waste disposal across the study area. Areas with the highest suitability scores, which indicate the most suitable sites for waste disposal considering climate change impacts, were identified. The suitability index is calculated for every point on the map, integrating all criteria and their respective weights. This spatially explicit map serves as a valuable decision-making tool, allowing stakeholders to assess and prioritize potential sites for solid waste disposal.

The suitability index (SI) is calculated using Equation (3.2) given by Feizizadeh *et al.* (2014):

$$SI = \sum_{i=1}^{m} \sum_{j=1}^{n} (X_{i.} W_{ij}) \qquad (3.2)$$

where:
SI is the suitability index for waste disposal sites, Xi is the normalized weight of the ith feature (criterion). Xi pertains to the overall importance assigned to each criterion in the analysis. It is a single weight representing the significance of the entire criterion, considering all its classes.
Wij is the normalized weight of the jth class of the thematic layer. Wj focuses on the importance of a specific class within a thematic layer. It provides a finer-grained perspective by considering the relative significance of different classes within a given criterion. m represents the total number of themes (criteria), and n is the total number of classes in a theme (thematic layer).

3.0 Result

In carrying out an Assessment of the impacts of Climate change on site selection for solid waste disposal, the methodology involved the weighted overlay that took reclassified spatial data layers and the weight obtained from the AHP as inputs for the analysis and the result of the analysis is presented in this section.

Figure 2 shows the trend of average annual temperature in the study area from 1979 to 2023. Starting from an average of approximately 298 K in 1979, the temperature has shown fluctuations but overall has increased to about 299.5 K by 2023. There are periods of slight decline, such as between 1990 and 2002, followed by significant increases from 2007. The dotted line represents a linear trend line with the equation $y=0.1971x+297.48$, where variables x and y represent the year and temperature values, respectively. The linear regression line indicates a gradual increase in temperature over the years. The rising temperature trend necessitates careful consideration in the siting, design, and operation of solid waste disposal sites to ensure environmental safety and operational efficiency in the study area.

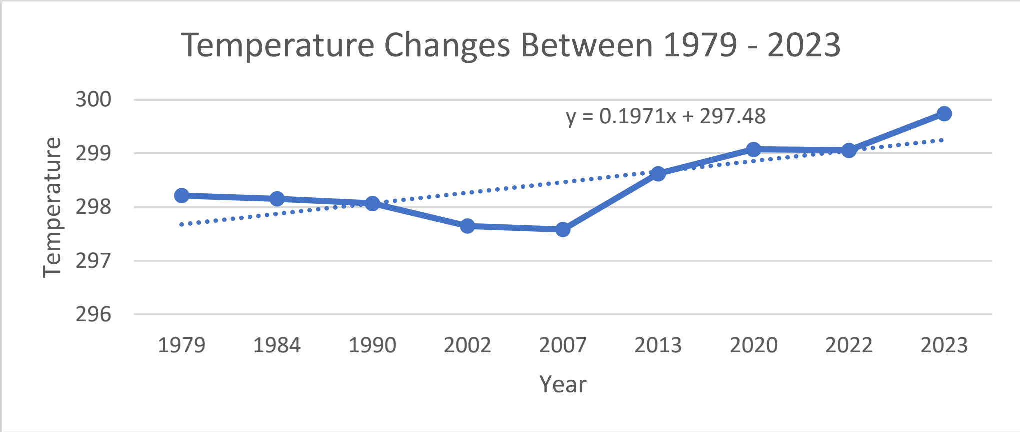

Figure 2: The trend of average annual Temperature in the study area.

Figure 3 shows illustrates the trend of average annual precipitation in the study area from 1979 to 2023. It is observed from figure 4.3 that the precipitation levels are fluctuated, starting at around 0.005mm in 1979 and showing minor declines with some peaks, notably around 2007. There is a noticeable peak in 2007, followed by a significant drop and subsequent minor fluctuations. The dotted line represents a linear trend line with the equation $y=-0.0001x+0.005$ where variable x and y representing year and temperature value respectively. The linear regression line suggests a slight decrease in precipitation over the years. The trend of slightly decreasing precipitation over the years, combined with notable fluctuations, underscores the need for adaptive and resilient planning for solid waste disposal sites

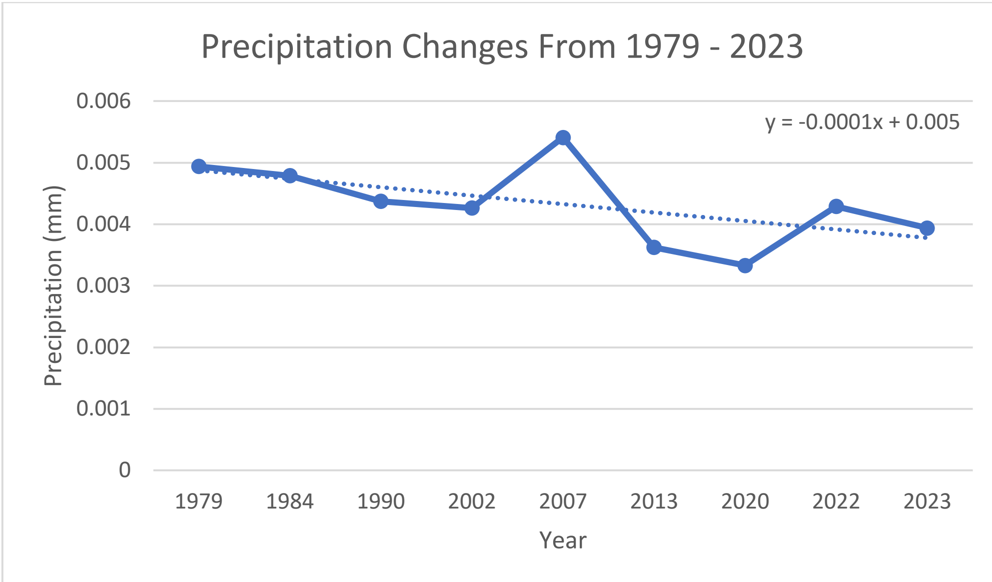

Figure 3: The trend of average annual Precipitation in the study area

Table 4.2: Land Cover Statistics of the Study Area from 2002 to 2023

Class	2002 Km^2	%	2007 Km^2	%	2012 Km^2	%	2017 Km^2	%	2023 Km^2	%
Water	5.019	0.16	7.645	0.24	6.522	0.20	5.302	0.17	5.789	0.18
Vegetation	1979.642	62.11	1976.767	62.02	1853.089	58.14	2244.629	70.42	1872.543	58.74
Built Area	278.619	8.74	281.867	8.84	495.231	15.54	574.741	18.03	703.568	22.07
Bare Land	579.385	18.18	566.495	17.77	500.177	15.69	338.935	10.63	514.593	16.14
Crops	344.41	10.81	354.741	11.13	332.474	10.43	23.815	0.75	91.443	2.87
Total	**3187.08**	**100**	**3187.52**	**100**	**3187.49**	**100**	**3187.42**	**100**	**3187.94**	**100**

Figure 4 shows the extent of land use types and changes in land use in the study area between 2002 and 2023, the study area was classified into five classes which are bare lands, Built Ups, Vegetation, Crops, Water Bodies. Table 4.3 to 4.7 shows the extent of land use types and changes in land use in the study area between 2002 and 2023.

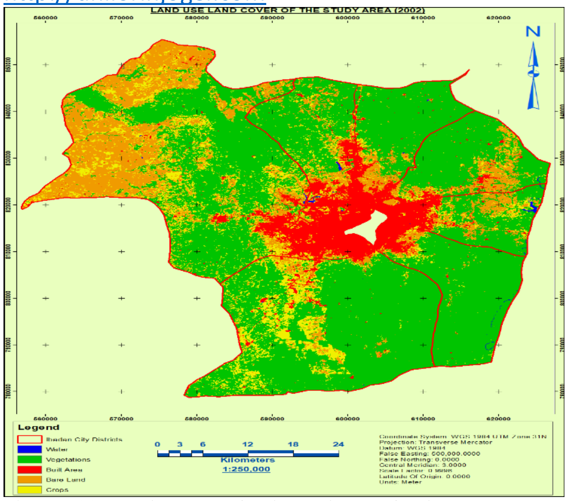

Figure 4(a): Land use map for the study area for the year 2002

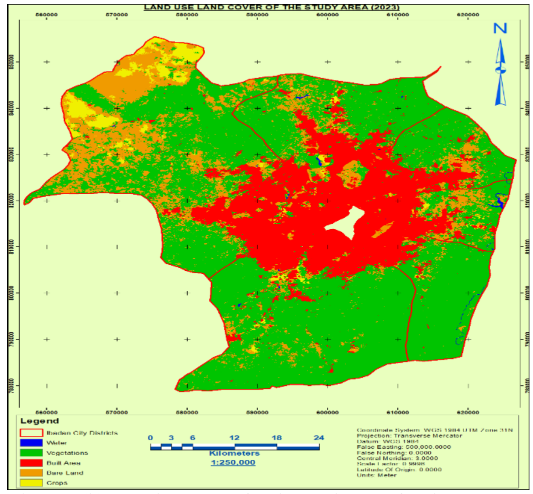

Figure 4(b): Land use map for the study area for the year 2023

Figure 5(a) shows the slope map of the study area. The visual representation of the elevation within the study area was classified into five classes and represented with different colors or symbols indicating different classes. Areas in deep green have a slope value ranging from 0 - 4.166, representing areas with very gentle slopes and these areas are almost flat. Areas in light green have a slope value ranging from 4.167 - 7.984, representing areas with gentle slopes and these areas have a slight incline. Areas in yellow have a slope value ranging from 7.095 - 12.84, representing areas with moderate slope. areas with orange have a slope value ranging from 12.85 - 24.65, representing areas with steep slope and these areas have a significant incline. Areas with red have a slope value ranging from 24.66 - 88.52, representing areas with very steep slopes.

Figure 5(b) shows the aspect map of the study area which was classified into seven different classes which are flat (-1), North (0 - 22.5), Northeast (22.5 - 67.5), East (67.5 - 112.5), Southeast (112.5 - 157.5), South (157.5 - 202.5), Southwest (202.5 - 247.5), West (247.5 - 292.5), Northwest (292.5 - 337.5) and North (337.5 - 360).

Figure 5(c) shows the proximity to water bodies, which is a critical factor in the siting of solid waste disposal sites due to the potential environmental and public health risks associated with improper waste management near water sources. Solid waste disposal sites generate leachate, a liquid that can percolate through waste material and carry harmful substances. A disposal site that is too close to water bodies can cause leachate to seep into the ground and contaminate surface and groundwater, posing serious health risks. In areas with significant rainfall or poor drainage, surface runoff can carry contaminants from the waste.

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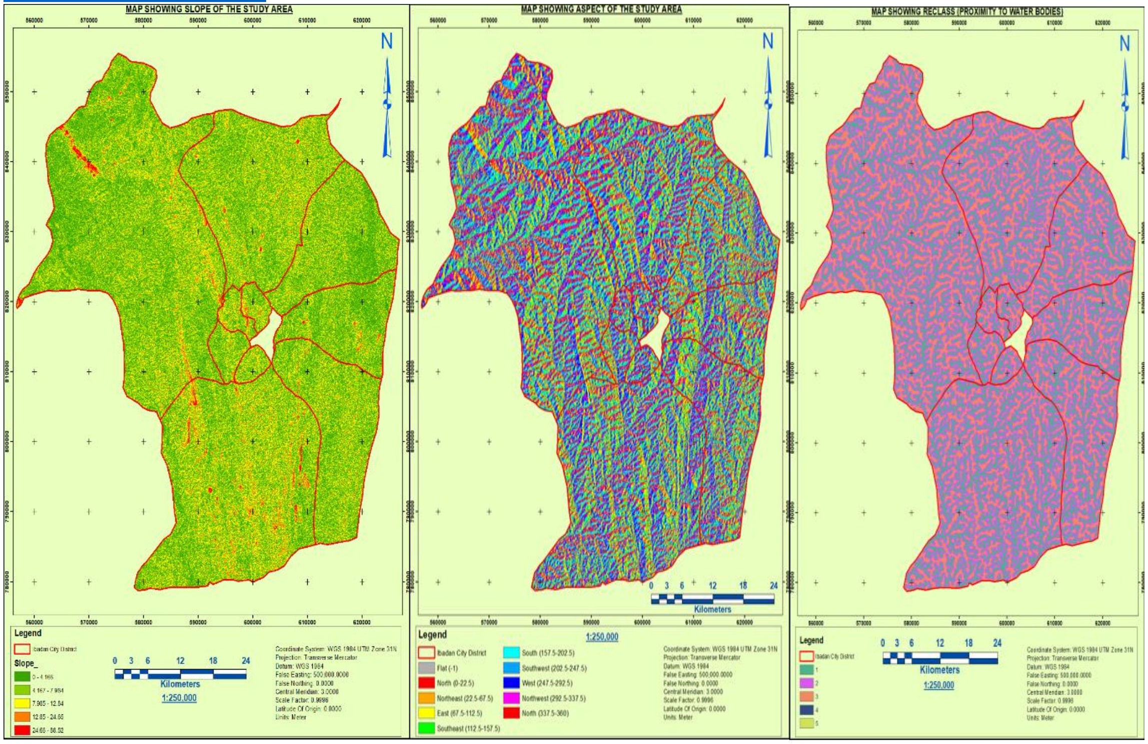

Figure 5: (a) slope (b) aspect (c) proximity to water bodies

Figure 6 shows the spatial distribution of existing dumpsites was examined to identify the location of existing dumpsites in the study area. Figure 4.5 presents the spatial distribution map showing the location of four major dumpsite sites located at Lapite, Awotan, Ajakanga and Aba – Eku was produced. It was discovered that the existing dumpsites are not uniformly distributed as some areas lack this dump sites which is not ideal for the study area.

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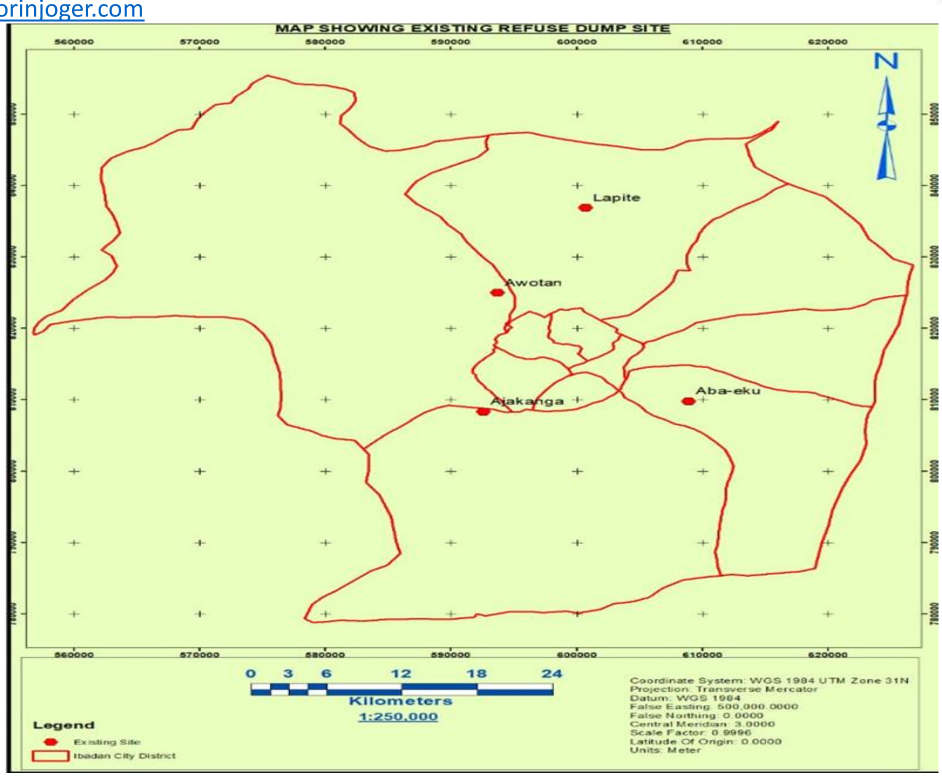

Figure 6: Map showing the Existing Solid Waste Disposal Sites

3.1 Results of the Analytical Hierarchical Process (AHP)

Analytical Hierarchical Process (AHP) was used in this study to determine areas suitable for solid waste disposal based on criteria considered in this study. The results derived from the AHP consist of the reclassified values of the criteria, the pairwise comparison matrix, and the Normalized version.

Table 2: Pairwise comparison of weighting the criteria

Criteria	Proximity to Road	Proximity to Water	LULC	Aspect	Slope	Temperature	Precipitation	%
Proximity to Road	1	5	1/3	3	5	1	1	**16.15%**
Proximity to Water	1/5	1	1/5	2	3	1	1	**8.98%**
LULC	3	5	1	5	4	1	1	**20.05%**
Aspect	1/3	1/2	1/5	1	1	1	1	**6.77%**

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Criteria	Proximity to Road	Proximity to Water	LULC	Aspect	Slope	Temperature	Precipitation	%
Slope	1/5	1/3	¼	1	1	1	1	**6.51%**
Temperature	1	1	1	1	1	1	1	**21.52%**
Precipitation	1	1	1	1	1	1	1	**20.02%**
Total	**0.07**	**0.14**	**0.04**	**0.14**	**0.16**	**0.07**	**0.07**	**100%**

Once all the criteria maps are normalized, the weights assigned to each criterion were computed and presented in Table 3. These weights are then used in the AHP to prioritize the criteria and assess site suitability for solid waste disposal. The final weights give the relative importance of each criterion in the decision-making process. Higher weights in Table 3 indicate more important criteria, which is temperature having the highest weight followed by LULC and precipitation.

Table 3: Normalized Pairwise comparison and weights of the criteria

Criteria	Proximity to Road	Proximity to Water	LULC	Aspect	Slope	Temperature	Precipitation	Weight	%
Proximity to Road	1	5	0.3	3	5	1	1	**0.1615**	**16.15%**
Proximity to Water	0.2	1	0.2	2	3	1	1	**0.0898**	**8.98%**
LULC	3	5	1	5	4	1	1	**0.2152**	**20.05%**
Aspect	0.33	0.5	0.2	1	1	1	1	**0.0677**	**6.77%**
Slope	0.2	0.33	0.25	1	1	1	1	**0.0651**	**6.51%**
Temperature	1	1	1	1	1	1	1	**0.2002**	**21.52%**
Precipitation	1	1	1	1	1	1	1	**0.2002**	**20.02%**
Total								**0.9997**	**100%**

3.2 Reclassification

The map of each criterion (precipitation, temperature and suitability map) for 2002-2023 was reclassified for uniformity purpose. The maps were classified into 4 classes. Class 1 – 4 stands for High, Medium, Low and Unsuitable.

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Figure 7 (a) and (b) shows the reclassified map for temperature and precipitation. Figure 7(a) shows the reclassified map of temperature for 2002. The map reclassifies temperature into four classes. The northeastern part of the study area has the lowest temperature. These areas might be suitable for activities or land uses that benefit from warmer conditions. The moderate suitable zone for temperature is areas are favorable but less intense than high-temperature zones. They can accommodate a range of activities that require moderate warmth.

Figure 7(b) shows the reclassified map of precipitation for 2002. Areas indicated with light red color are highly suitable for solid waste disposal site. Yellow region of the map shows the areas that are moderately suitable for siting solid waste disposal sites in the study area. The region showing green and blue color are low and unsuitable region for siting solid waste disposal sites respectively.

Figure 7(c) presents the site suitability map for solid waste disposal for 2002. It is observed that very few areas are marked as highly suitable for solid waste disposal. The largest concentration of high-suitability areas is in the southwestern part of the region. Medium suitability zones are scattered throughout the central and eastern parts of the region. These areas are more widespread but still limited compared to the low suitability regions. Most of the region falls under the low suitability category. This indicates that while these areas can be considered for solid waste disposal, they are not ideal.

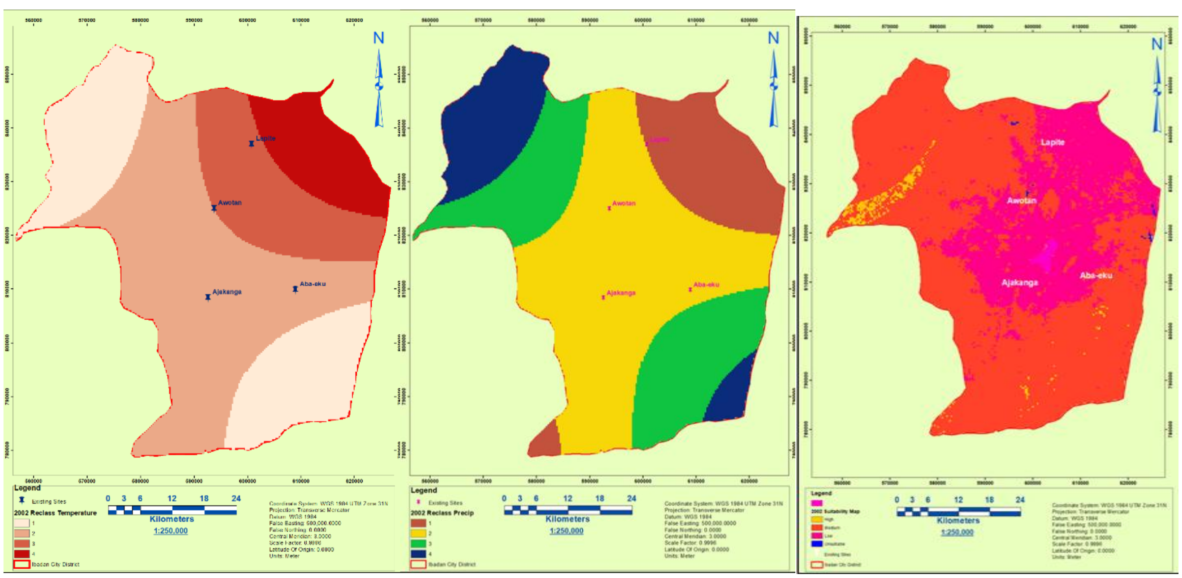

Figure 7: (a) Reclassified Temperature for year 2002 (b) Reclassified precipitation for year 2002 (c) Reclassified suitability map for year 2002

Figure 8(a) shows the reclassified map for temperature and precipitation for 2023. Figure 8(a) shows the reclassified map of temperature for 2023. The northeastern part of the study

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area is highly suitable. Moderate suitable zones cover the large area of the study area which is the central part of the study area. Low suitable and Unsuitable zones are found at northwestern and Southeastern part of the study area.

Figure 8(b) shows the reclassified map of temperature for 2023, Areas indicated with light red color are highly suitable for solid waste disposal site. This area is at the southern region of the study area. Yellow region of the map shows the areas that are moderately suitable for siting solid waste disposal sites in the study area. The region showing green and blue color are low and unsuitable region for siting solid waste disposal sites respectively.

Figure 8(c) presents the site suitability map for solid waste disposal for 2023. It is observed that the high-suitability areas have decreased drastically compared to the 2020 map and there is a notable cluster of high-suitability areas around Lapite. The medium suitability zones have further expanded, especially in the central, Northwestern and southeastern parts of the region. These areas cover a significant portion of the map, indicating a broader distribution of moderately suitable zones for solid waste disposal. The majority of the region remains in the low suitability category. However, there is a noticeable reduction in the extent of low suitability areas compared to previous years as more regions have transitioned to medium and high suitability. Unsuitable areas remain minimal on the map, similar to previous years, indicating that most of the region is considered suitable to some extent for solid waste disposal.

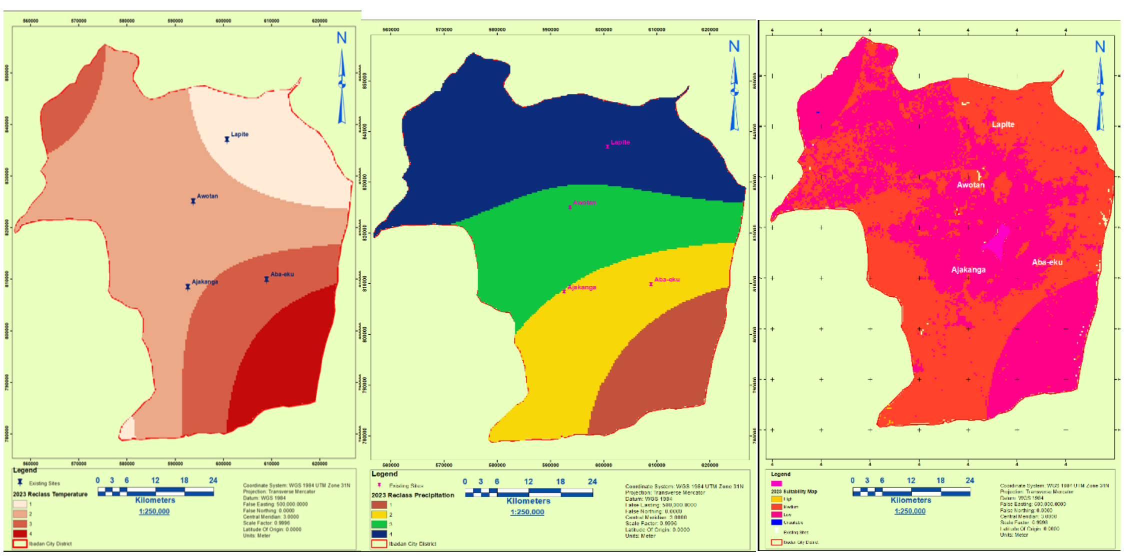

Figure 8: (a) Reclassified Temperature for year 2023 (b) Reclassified precipitation for year 2023 (c) Reclassified suitability map for year 2023

The area of the high and moderate suitable zones for each year were added together to give the area (Hectares) presented in Table 4.

Table 4: Area of Suitable zones and Average Temperature and Precipitation

Year	Suitable Area (Hectares)	Average Temperature (Kelvin)	Average Precipitation (mm)
2002	21783	298.6202935	0.004312992
2007	21231	297.5849485	0.005439667
2013	18571	298.6202935	0.003624344
2020	15745	299.0752005	0.003330038
2023	15277	299.0578485	0.004289006

The graph of the area and average temperature and precipitation were plotted to show relationship between area of suitable zones and average temperature and precipitation for each year. Figure 9 shows the line graph of area of suitable zones and average temperature for year 2002 – 2023. It is discovered from the line graph that a decrease in average temperature leads to a decrease in area of suitable zones for solid waste in the study area while an increase in average temperature leads to an increase in area of suitable zones for solid waste in the study area.

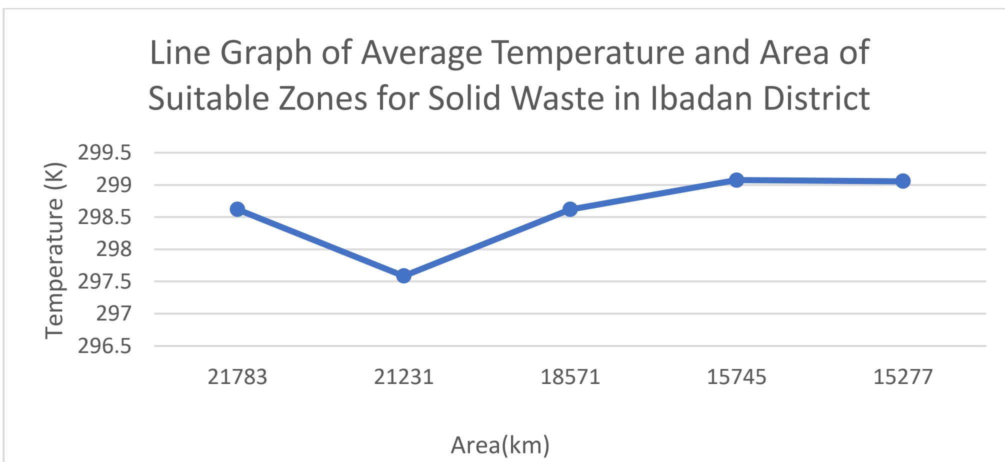

Figure 9: Line graph of area of suitable zones and average temperature for year 2002 – 2023

Figure 10 shows the line graph of area of suitable zones and average temperature for year 2002 – 2023. It is discovered from the line graph that a decrease in average precipitation leads to an increase in area of suitable zones for solid waste in the study area while an increase in average precipitation leads to a decrease in area of suitable zones for solid waste in the study area.

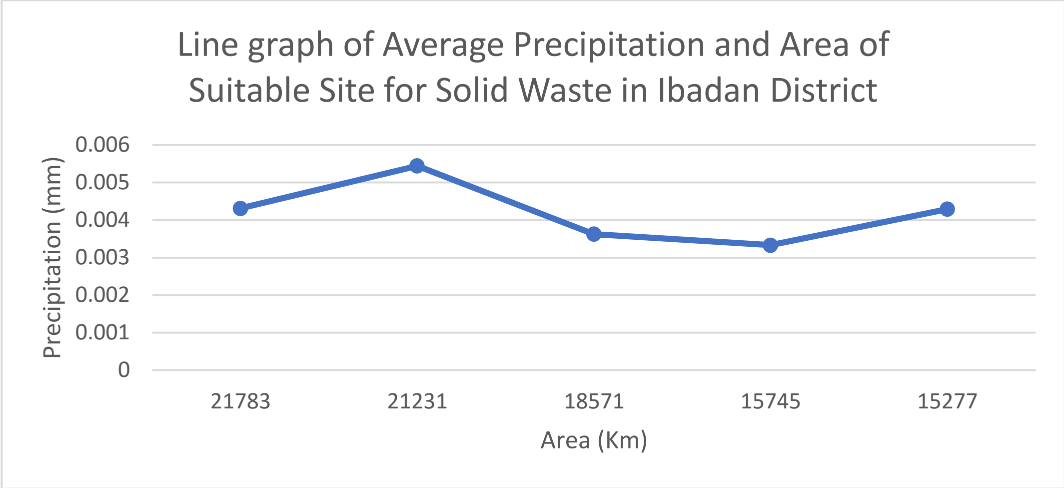

Figure 10: Line graph of area of suitable zones and average precipitation for year 2002 – 2023

Figure 11 shows the proposed new sites for solid waste disposal in the study area. From Figure 11 high Suitability Zone is represented by the green color on the map. These areas are highly suitable for solid waste disposal. Factors such as lower population density, appropriate distance from water bodies, and favorable environmental conditions might contribute to this high suitability. Moderate Suitability Zone is represented by the yellow color on the map. These areas are moderately suitable for solid waste disposal. There might be some constraints or factors that are not ideal, but with proper management and mitigation measures, these areas can be used for waste disposal. Low Suitability Zone is represented by the red color on the map. These areas are not suitable for solid waste disposal. High population density, proximity to water bodies, unfavorable environmental conditions, and other factors likely make these areas unsuitable for waste disposal.

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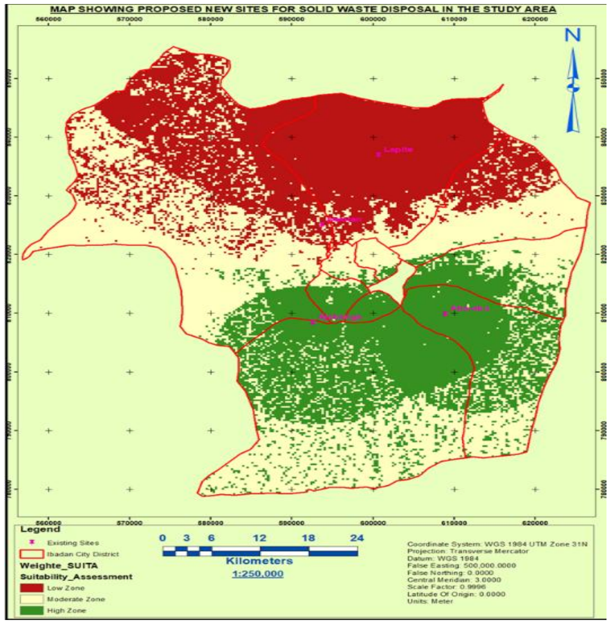

Figure 11: Map showing proposed new sites for solid waste disposal

3.2 Discussion

In this research, the spatial distribution of existing dumpsites was examined to identify the location of existing dumpsites in the study area. So, the spatial distribution map showing the location of four dumpsite sites located at Lapite, Awotan, Ajakanga and Aba – Eku was produced. It was discovered that the existing dumpsites are not uniformly distributed as some areas lack this dump sites which is not ideal for the study area.

The study identifies four climatic conditions that impact solid waste disposal sites: temperature, precipitation, wind, and humidity. High temperatures can increase moisture evaporation, reducing leachate volume but potentially concentrating contaminants. Low temperatures can slow decomposition, reducing leachate production and gas generation. Frozen conditions limit microbial activity, slowing waste stabilization. Warm temperatures intensify odors from decomposing waste, necessitating odor control measures. Heavy rainfall can cause soil erosion at landfill sites, exposing waste materials and disrupting cover integrity. Wind can disperse lightweight materials, causing environmental pollution and public health concerns. High humidity levels accelerate organic material breakdown and increase landfill gas production. These conditions can amplify odors from decomposing waste.

The historic climate data was used to perform trend analysis to determine the climatic change in the study area from 1979 to 2013. The average annual temperature in the study area from 1979 to 2023 shows fluctuating levels, starting from 298 K in 1979 and increasing to 299.5

K by 2023. There have been periods of slight decline, but significant increases since 2007. The linear regression line with the equation $y = 0.1971x + 297.48$ where variable x and y representing year and temperature value respectively shows a gradual increase in temperature over the years. Elevated temperatures can intensify odors and attract vermin, so suitable sites should be located away from residential areas and equipped with odor control measures. Rising temperatures contribute to the urban heat island effect, so waste disposal sites should be chosen in areas with existing vegetation cover to mitigate this effect. Therefore, careful consideration is needed in the siting, design, and operation of solid waste disposal sites to ensure environmental safety and operational efficiency.

The study area's average annual precipitation from 1979 to 2023 also shows fluctuating levels, starting with 0.005mm in 1979 and showing minor declines with peaks around 2007. A noticeable peak in 2007 followed by a significant drop and minor fluctuations. The linear regression line with the equation $y = -0.0001x + 0.005$ suggests a slight decrease in precipitation over the years, highlighting the need for adaptive and resilient planning for solid waste disposal sites. Areas experiencing significant precipitation fluctuations may face challenges in maintaining site stability, especially during heavy rain events that can cause erosion or structural issues. Designing disposal sites that are resilient to changing water availability is essential, involving water conservation measures and ensuring the site can handle varying precipitation levels without environmental contamination.

In carrying out site suitability assessment to identify suitable areas for solid waste disposal based on climate change in the study area, land use analysis, terrain analysis, and climate change analysis were done. In the land use analysis, the study area was divided into five classes: Bare lands, Built Ups, Vegetation, Crops, and Water Bodies. The bare lands area decreased from 579.385 km^2 in 2002 to 338.935 km^2 in 2023. Built Ups increased from 278.619 km^2 to 574.741 km^2 from 2002 to 2023. Vegetation and crops covered a smaller area, with vegetation decreasing from 62.11% to 11.12% in 2007 and crops increasing from 332.474 km^2 to 91.443 km^2 in 2023. Water bodies covered a smaller area, from 5.019 km^2 in 2002 to 5.789 km^2 in 2023. The terrain analysis reveals moderate and steep slopes in most areas, which can be suitable for waste disposal with significant engineering interventions. Controlling erosion and managing leachate is crucial, while stabilization techniques may be needed for long-term site stability. Steep slopes are less suitable due to erosion risk and construction difficulties.

From the proximity to water analysis, it was discovered that Solid waste disposal sites generate leachate, a liquid containing harmful substances. Disposal site that has close proximity to water bodies can cause contamination, posing health risks. In areas with significant rainfall or poor drainage, surface runoff can harm aquatic ecosystems.

The maps produced from the above analyses were overlaid using AHP to identify areas that are suitable for solid waste disposal. It was revealed that High Suitability Zone is predominantly located in the southern part of the study area, including regions such as Ona-

Ara, Oluyole, and parts of Egbeda. These areas should be prioritized for establishing solid waste disposal sites due to their high suitability. Moderate Suitability Areas are scattered throughout the central parts of the study area. Regions such as Ibadan South and parts of Ibadan South-East fall into this category. With careful planning and proper management practices, these areas can be utilized for waste disposal. Low Suitability Areas are mostly located in the northern part of the study area, including Akinyele and parts of Lagelu. These areas should generally be avoided for solid waste disposal due to their low suitability.

4.0 Conclusion

This research aims to assess the impacts of climate change on site selection for solid waste disposal for effective and sustainable solid waste management in Ibadan, Oyo State. Historical climate data was used to analyze climatic changes from 1979 to 2013, focusing on temperature and precipitation trends. The study area's average annual temperature from 1979 to 2023 has fluctuated, starting at 298 K in 1979 and increasing to 299.5K by 2023. There have been periods of decline, but significant increases since 2007. The linear regression line shows a gradual increase in temperature over the years. Dumpsites should be located at safe distances from water bodies and have proper drainage systems to manage surface water runoff.

The study area's average annual precipitation from 1979 to 2023 shows fluctuating levels, with a slight decrease over the years. This suggests the need for adaptive and resilient planning for solid waste disposal sites. Areas with significant precipitation fluctuations may face challenges in site stability, erosion, and structural issues.

A site suitability assessment was conducted using land use analysis, terrain analysis, and climate change analysis. The study area was divided into five classes: Bare lands, built-ups, vegetation, Crops, and Water Bodies. The terrain analysis revealed moderate and steep slopes in most areas, which could be suitable for waste disposal with significant engineering interventions. The maps produced were overlaid using AHP to identify areas suitable for solid waste disposal.

The maps produced from the above analyses were overlaid using AHP to identify areas that are suitable for solid waste disposal. It was revealed that the High Suitability Zone is predominantly located in the southern part of the study area, including regions such as Ona-Ara, Oluyole, and parts of Egbeda. These areas should be prioritized for establishing solid waste disposal sites due to their high suitability. Moderate Suitability Areas are scattered throughout the central parts of the study area. Regions such as Ibadan South and parts of Ibadan South-East fall into this category. With careful planning and proper management practices, these areas can be utilized for waste disposal. Low Suitability Areas are mostly located in the northern part of the study area, including Akinyele and parts of Lagelu. These areas should generally be avoided for solid waste disposal due to their low suitability.

4.1 Recommendation

Based on the result of analysis in this research, we recommend that more waste disposal sites should be sited at areas identified as high suitability zones for more efficient and flexibility in waste management practices. Regular updates to waste management plans should be made to reflect the latest climate data and projections, ensuring that site selected remains resilient to changing climatic conditions.

The establishment of a robust system for continuous collection and monitoring of climatic and environmental data relevant to suitable waste disposal sites is highly recommended. This includes temperature, precipitation, soil moisture, and other critical parameters that influence site suitability. Implement remote sensing and GIS technologies for real-time monitoring and assessment of waste disposal sites, allowing for prompt responses to any adverse climatic impacts.

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