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Delineation of Landfill Sites for Municipal Solid Waste Management using GIS

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Abstract

The use of landfills has been applauded in municipal solid waste management as a critical solution to open dumping and burning. Selection of suitable landfill sites presents a challenge as it involves integration of numerous criteria in waste management and sustainability template without prejudice to the environment. The aim of this paper is to delineate appropriate sites for landfills in the basement complex of Ado-Ekiti, South-western Nigeria. The need for landfill sites that meet scientific and environmental requirements is compelling. Landsat-8 OLI & TIRS images of 2016 and ASTER imagery (30m resolution) were acquired to generate land use/land cover maps and site selection criteria. The composite image was subjected to supervised classification using the maximum likelihood algorithm in ArcGIS 10.2.2. The classification permitted the extraction of the land use of urban areas (settlements), agricultural areas, and bare land. Geoelectrical characterization was deployed to produce *in situ* data. Integration of data using a weighted overlay yielded a landfill suitability index map that classified the area into four categories of unsuitable, partly suitable, moderately suitable, and very suitable locations of landfill sites. Sanitary landfills are desirable to mitigate the adverse effects of widespread open dumping.

Keywords: Basement Complex; Landfill; Suitability Analysis; Geospatial Technique; Municipal Solid Waste.

1. Introduction

Waste management—the collection, transportation, processing, recycling, or disposal of waste materials—is central to the environment, human health, and local aesthetics. Waste management has increasingly become a major concern in most cities in developing countries, including Ado Ekiti Southwest Nigeria [1-3]. According to Iorhemen et al. [4], the current method of municipal solid waste (MSW) treatment across most Nigerian cities remains open burning at disposal sites. Ferronato & Torretta [5] decried open dumping and open burning as the usually implemented waste treatment and final disposal systems in low-income countries. Solid waste disposal has been identified as one of the most serious environmental problems facing many cities in Nigeria [4, 6, 7].

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Prevalently, disposal of solid waste in Ado Ekiti has been by open dumping. This primitive method is known to attract flies, vermin, and scavengers. The dumpsite is characterized by offensive odours which often serve as an early indicator of health hazards [8, 9]. To overcome this phenomenon and protect the environment, it is crucial to delineate appropriate landfill sites for the metropolis. Landfills have been recognized as the classic solution for waste disposal [10-12]. Owoeye & Rotowa [13] recommended the use of an engineering landfill device for waste disposal to discourage open dumping. Kofoworola [14] reported a significant reduction of greenhouse gas emissions resulting from the current MSW management of open dumping and burning with the implementation of disposal strategies such as sanitary landfill with gas capture.

According to Ferronato & Torretta [5], environmental contamination due to solid waste mismanagement is a global issue. The volume of waste generation in Ado Ekiti metropolis which stood at about 120 tons per day a decade ago has increased drastically along the trend of urbanization and the negative consequences of urban sprawl [15]. Figure 1 shows an active dump site at Ilokun, Ado Ekiti. It is apparent that the site decreases the aesthetic value of the environment [6, 16].

Figure 1. Burning at the Ilokun dumpsite, Ado Ekiti (*https://gazettengr.com/ekiti-dumpsite*)

Tinuola & Owolabi [17] observed an increase in environmental pollution with urbanization in Ekiti State. The highest percentage of pollution was reported in Ado-Ekiti, with an alert on possible health hazards to the residents. Ige & Adetunji [18] examined the relationship between some socio-economic factors and household sanitation in Ado-Ekiti. An indifferent status was observed for the general attitude of the residents towards household sanitation and waste disposal. Increasing population and the attendant human activities have geometrically led to increasing waste tonnage since the creation of Ekiti State in October 1996 and the establishment of the state capital at Ado-Ekiti. The use of controlled sanitary landfills is desirable to mitigate the adverse effects of open dumping and burning and ultimately safeguard public health and the environment [13-15].

Landfill site selection is acknowledged as a complicated process as it entails consideration of a large number of variables [1, 5]. It is a tasking enterprise particularly in the basement complex terrain which is known to be hydrogeologically challenging with hydraulic properties characterized by extreme variations over short distances [19-21]. Environmental protection and public health considerations are the primary concerns in landfill site selection [3, 11, 22]. An appropriate landfill site selection demands an ensemble of spatial and urban planning requirements, hydrogeological conditions, and geological conditions [1–3]. Integration of geoelectrical and remotely sensed data in a Geographical Information System (GIS) holds good promises.

The application of satellite imagery offers immerse advantages in the selection of suitable sites for waste disposal. Satellite remote sensing permits repetitive and synoptic coverage, among other features. GIS has emerged as an indispensable technology in environmental studies and management. It is readily applied to manipulate and analyze geographic data. It is a powerful tool for collecting, storing, retrieving, analyzing, displaying, and transforming spatial data as required [1, 2, 7]. GIS is reputable for its ability to manage large volumes of spatial data from different sources. With the implementation of GIS, a large volume of geospatial data and information are maintained in a standard format, revised, and updated with additional features. Sustainable development and management are thus facilitated at real time [3, 11, 20].

This paper presents an integration of remotely sensed data, soil type, geological, and geoelectrical data carried out in a GIS environment with a view to developing a suitability map for the location of landfill sites in Ado Ekiti, Southwestern Nigeria.

2. Description and Geology of the Study Area

Ado-Ekiti, South-western Nigeria, lies within latitudes 7° 33′ and 7° 42′ N and longitudes 5° 11′ and 5° 20′ E (Figure 2). Ado-Ekiti doubles as a local government council headquarter and the State Capital of Ekiti State. The metropolis is the hub of economic activities, banking and government civil service in the state.

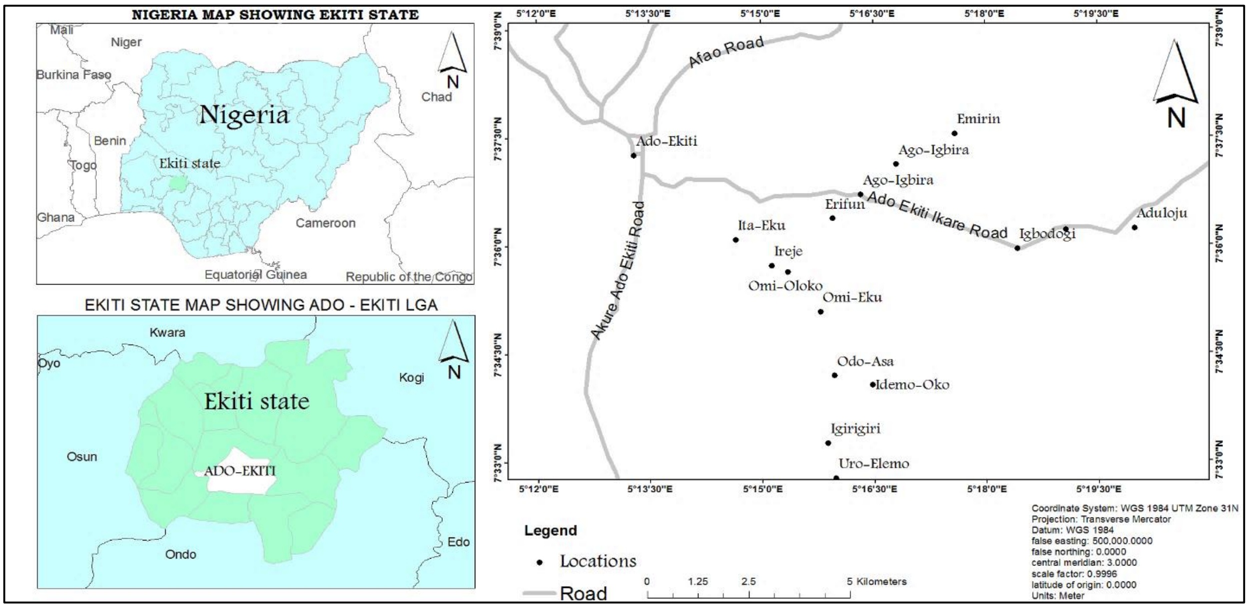

Figure 2. Location map of the study area

The area is underlain by the basement complex of Southwestern Nigeria comprising the migmatite–gneiss–quartzite complex, charnockitic and dioritic rocks, older granites and unmetamorphosed dolerite dykes (Figure 3). The region experiences a tropical climate with mean annual temperature of 27°C and distinct wet and dry seasons. About 75% of all rainfall events are of moderate to high intensities. Light showers of less than 10 mm/hr account for only 25%. The major rivers and streams draining the area include Alamoji, Elemi, Ireje; Omisanjana and Awedele Streams [20, 23, 24].

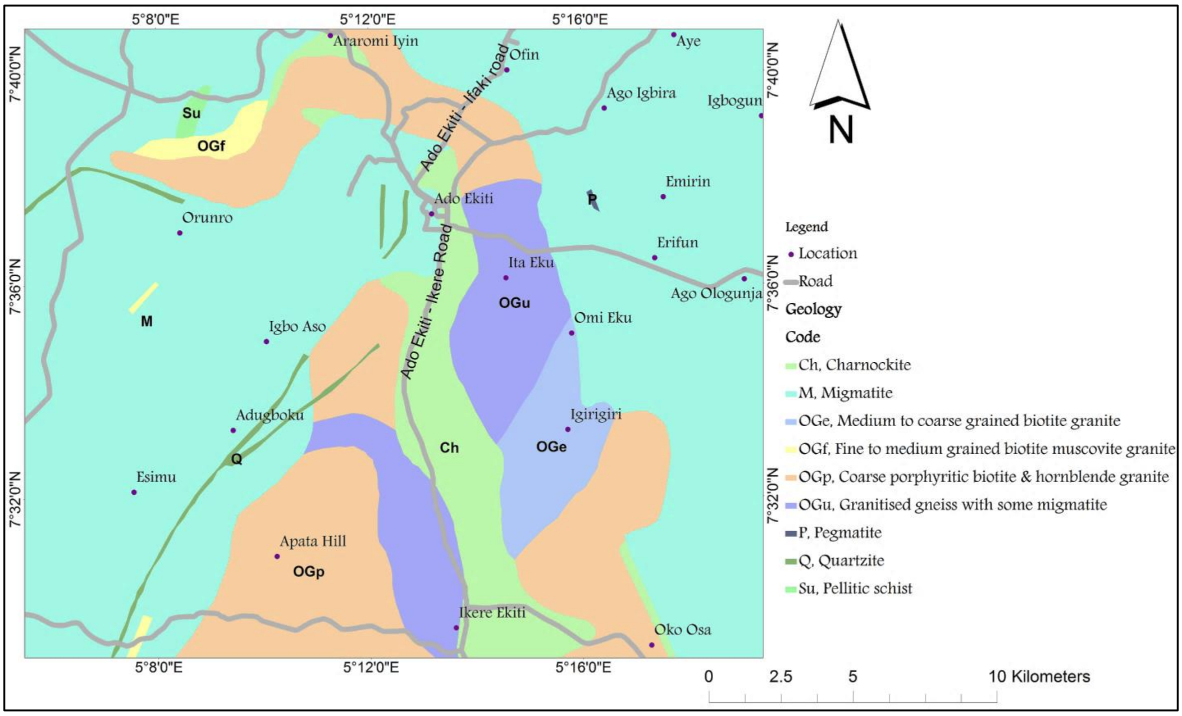

Figure 3. Geological map of Ado-Ekiti. After NGSA; Geological map of Akure Sheet 56, 1966

3. Materials and Methods

The reconnaissance survey was carried out in two phases; office reconnaissance and field reconnaissance to obtain first-hand information. Secondary data sources were accessed. The field reconnaissance involved familiarization with the physical terrain, and in effect, determine the arrangement of the attributes required to facilitate the optimum identification of the candidate landfill sites. Data were obtained through direct acquisition from the field as well as satellite imagery. The methodology entailed creation of land use/cover maps and site selection criteria using weighted overlay. Nine criteria in line with the scientific and environmental requirements for landfill sites were adopted in the study. These criteria included lithology, geomorphology, slope, soil, distance from major roads, distance from major streams, land use / land cover, and overburden thickness.

Landsat-8 OLI & TIRS image, path 191, row 55 of 2016 was acquired through USGS online data facility. False color composite of the image was performed. The composite image was subjected to supervised classification using maximum likelihood algorithm in ARCGIS 10.2.2 [25, 26]. The land use of urban area (settlements), agricultural area and bare land were extracted. ASTER imagery (of 30 m resolution) was employed to obtain the elevation and slope of the study space. The lineament density map was generated using line density function in ARCMAP. Geological map obtained from Nigeria Geological Surveys Agency enabled identification of the rock types. The major soil associations found in the study area were extracted from Nigeria Federal Survey Soil map. Topographic map at a scale of 1:50,000 permitted the delineation of the river systems within the study area. ArcGIS Euclidian Distance was employed to generate the surface water map and road map [2, 20, 27]. To perform the integrated weighted overlay analysis, various thematic layers were created, re-classified and assigned suitability weightages on the basis of the relative significance and importance in landfill siting [1, 11, 12]. The processing flow chart is presented in Figure 4.

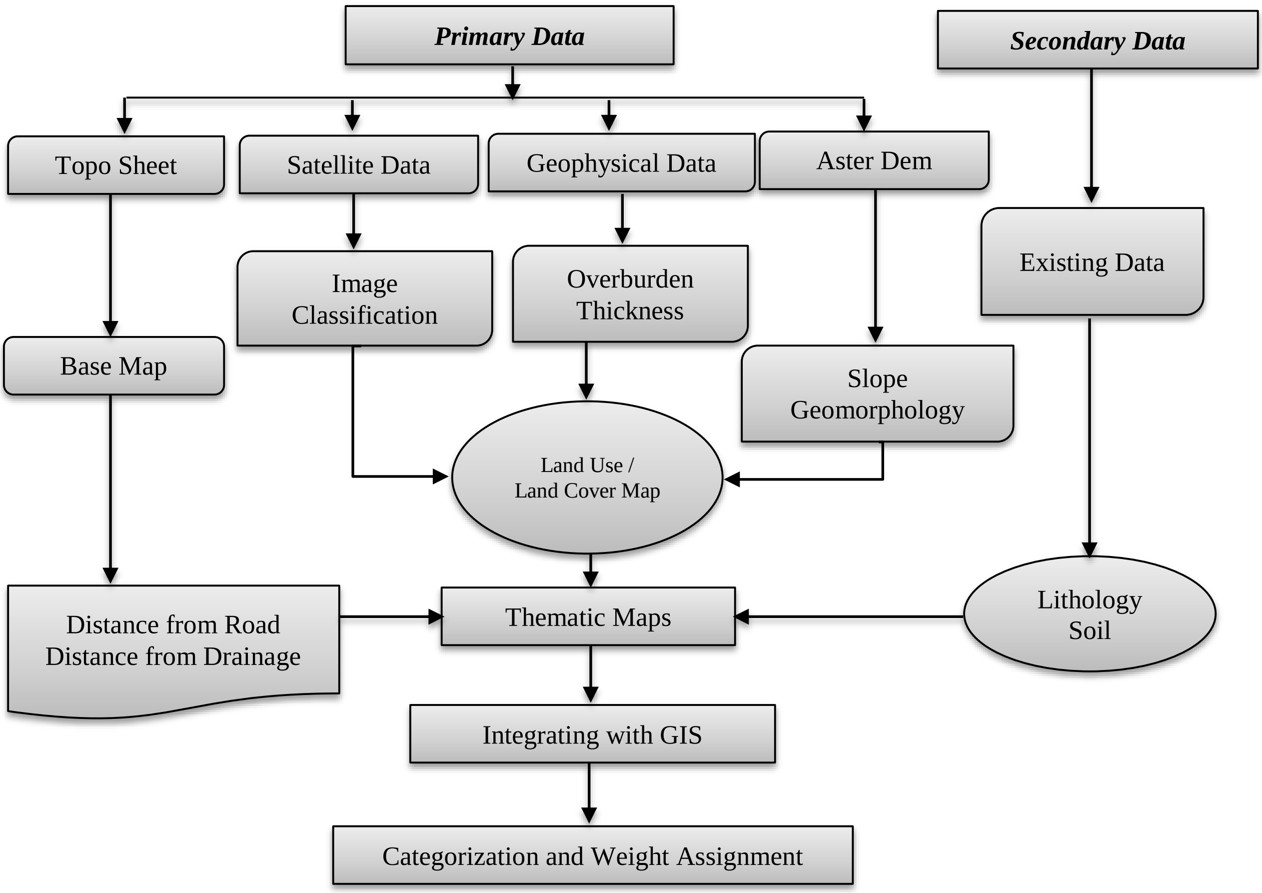

Figure 4. The processing flow chart

4. Results and Discussion

Lithology, geomorphology, slope, soil, lineament, distance from major roads, distance from major streams, land use / cover and overburden thickness formed the data base for site selection criteria for landfills in consonance with scientific and environmental requirements.

4.1. Geological Weightage

The major lithologic units in the study area are migmatite-gneiss, granite, quartzite and charnockite (Figure 5). The migmatite-gneiss complex is less brittle compared with quartzite resulting in less development of fractures. Quartzites occur mainly as minor elongated bodies within the massive migmatite-gneiss and charnockite. Quartzite is associated with intense fracturing, high secondary porosity, and good aquifer properties. It is ranked highest in terms of groundwater vulnerability to pollution; and lowest suitability for landfill. Charnockite and granites are the youngest rock types. The charnockite-derived soils are clayey and silty in nature and thus possess low permeability. Granite and migmatite gneiss-derived soils are sandy and gravely with low clay content. The charnockite rocks are ranked highest in landfill suitability considerations [23, 27].

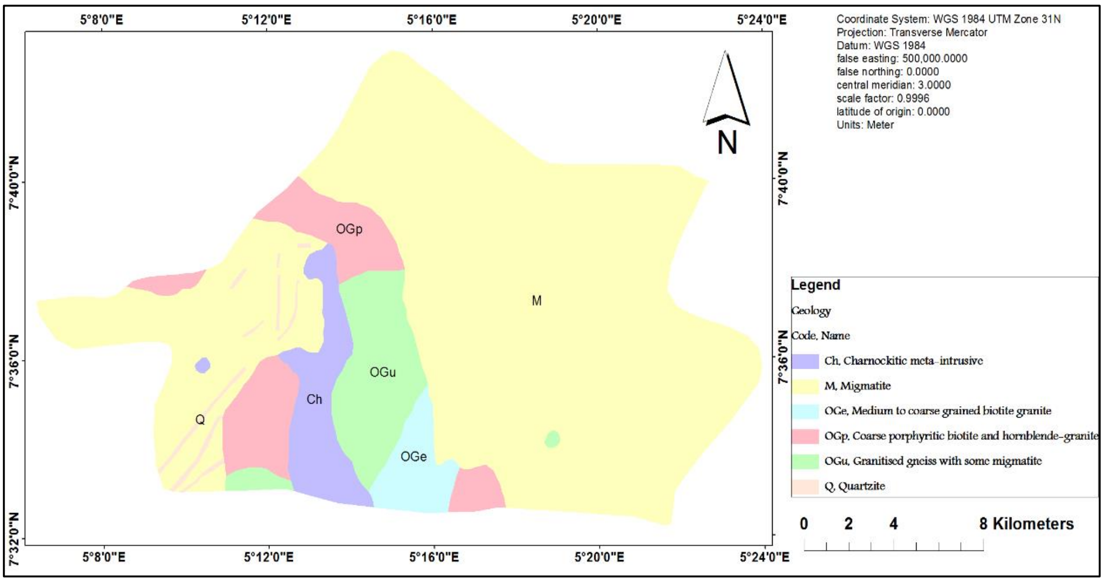

Figure 5. Geological map of the study area

4.2. Slope Weightage

Slope of the terrain plays an important role in solid waste disposal site identification as it has a direct impact on the run-off. Run offs are accentuated by increasing slope. As slope increases the runoff volume increases. Debris, wastes and effluents on the high slope flow according to slope and constitute health hazards to the low-lying areas and adjacent plains [7, 12, 28]. The slope quantity derived was reclassified into applicable categories. The suitability ranking for a candidate landfill site decreases with increasing slope. Regions with slope between 0° and 4.8° were classified as flat and ranked the most suitable for landfill siting. Regions with slope ranging from 4.8–8.92° were classified as gentle slope, regions with slope ranging from 8.92° - 13.77° were classified as having moderate slope, regions with slope ranging 13.77–21.34 ° were classified as steep slope and regions with slope 21.34°- 49.46° were classified as very steep slope (Figure 6).

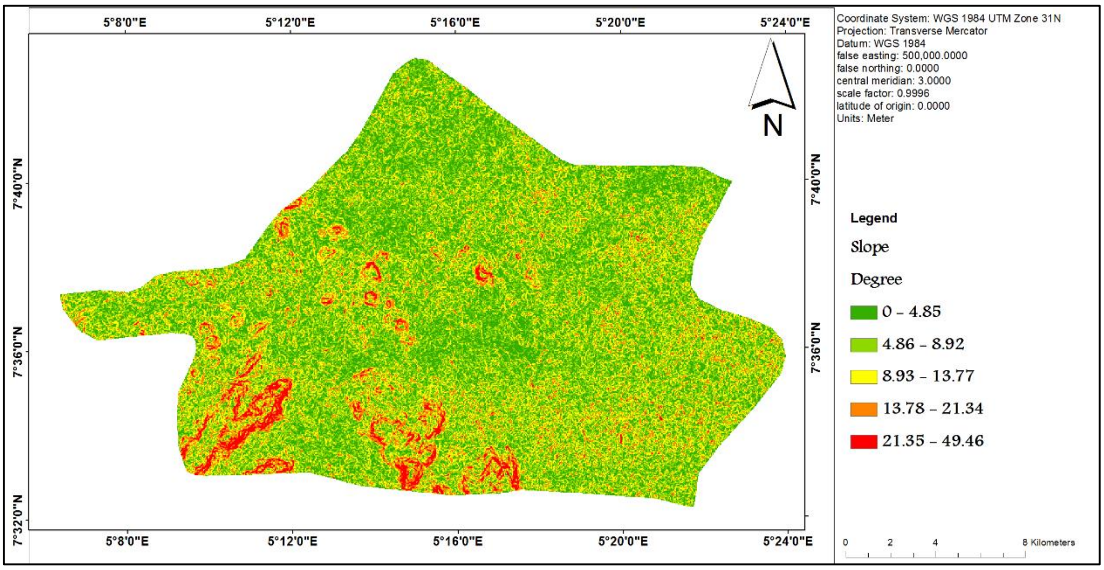

Figure 6. Slope map of the study area

4.3. Geomorphological Weightage

The geomorphological map, Figure 7, shows four geomorphological units including residual hills with elevations of 548 – 741 m above sea level (m.a.s.l.) and the pediments located at the foot of the residual hills with elevations in the range of 457 – 548 m.a.s.l. The relatively high elevation geomorphological units constitute the watershed for the streams and rivers. The pediplain and etchplain with elevations of 385 – 457 m.a.s.l and 333 – 385 m.a.s.l., respectively fall within and around the stream/river channels. The etchplain is ranked least in suitability for landfill siting. Pediplain is considered suitable only amidst other variants [20, 22, 27].

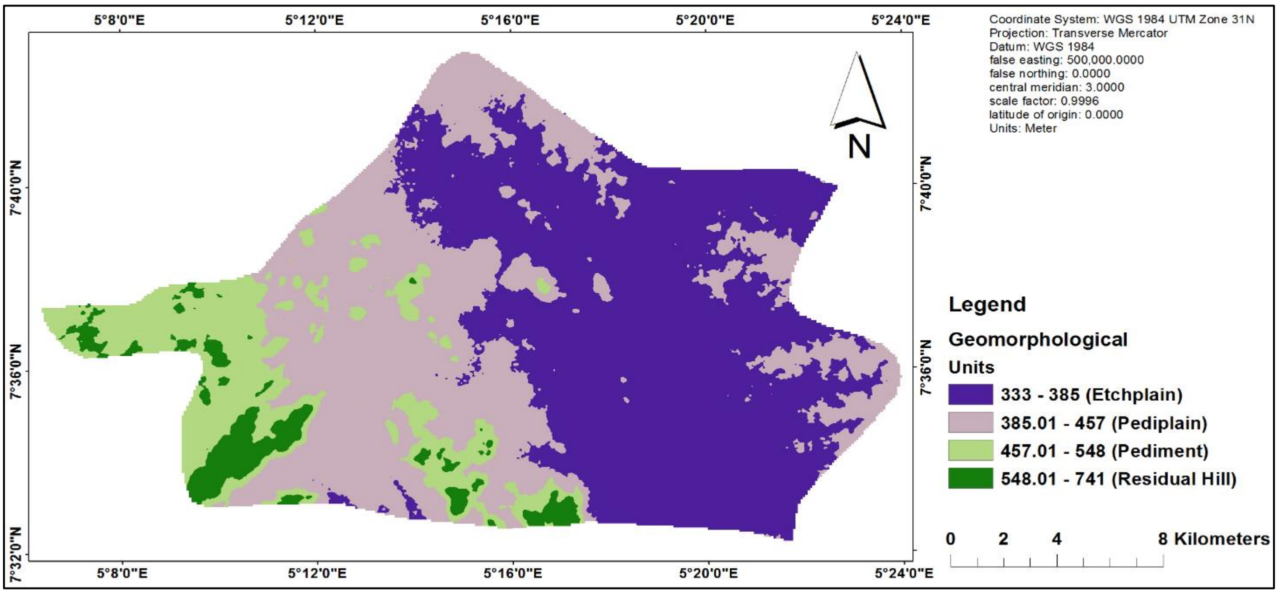

Figure 7. Geomorphological map of the study area

4.4. Drainage Weightage

Water resources protection demands that landfills be sited at considerable distance away from rivers/streams to avert leachate contamination [9, 16, 29]. Euclidean distance function was deployed to compute distance to rivers. Figure 8 shows the drainage map of the study area. Subsequent reclassification permitted the suitability ranking according to this criterion with high weight attributed to low drainage density areas and low weight to high drainage density zones. The drainage density map was prepared using the ArcGIS spatial analyst.

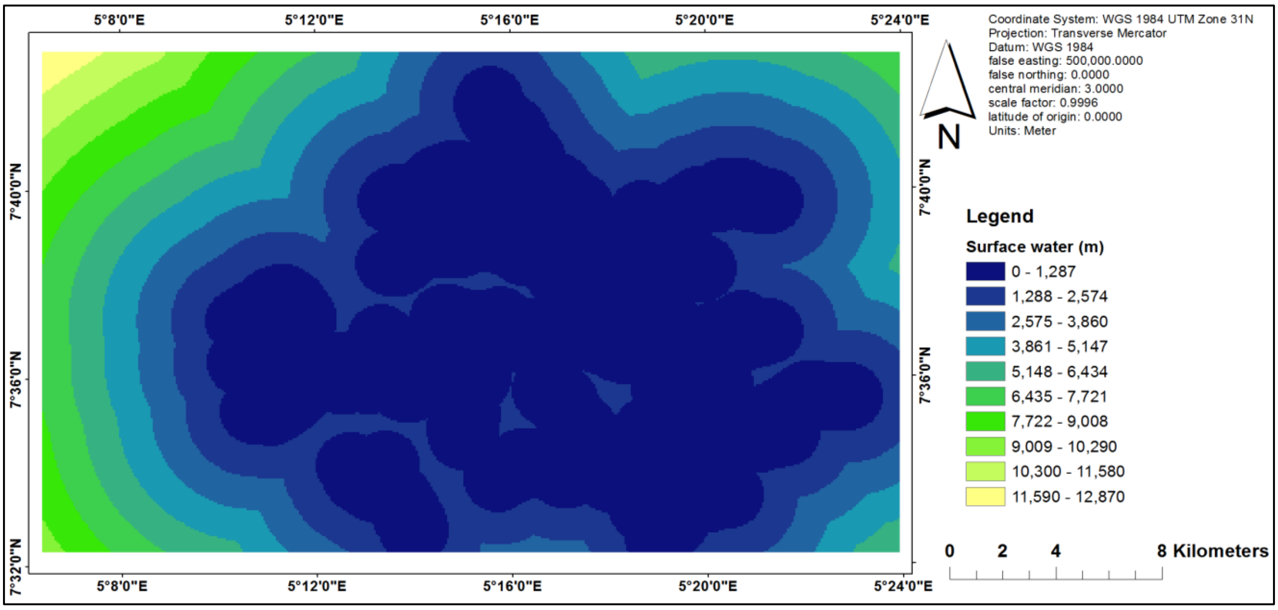

Figure 8. Drainage map of the study area

4.5. Road Weightage

Landfill siting takes into account the human settlement, landscape and transportation of the waste. Good planning demands that landfill sites should be accessible under any conditions, hence good road network is desirable. The costs associated with transportation should be economical. On the other hand, landfill sites at close proximity to the road, present aesthetical challenges [7, 12, 22]. Candidate landfill site suitability weightage is given accordingly and suitable score given to the distances (Figure 9).

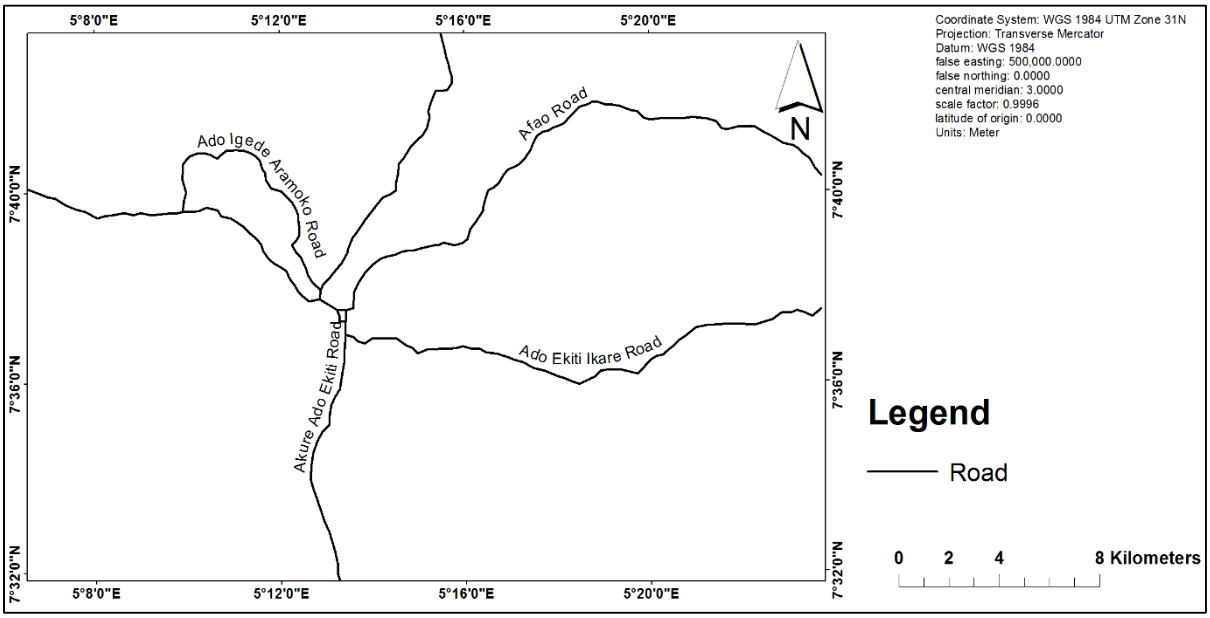

Figure 9. Road map of the study area

4.6. Structure and Lineaments Weightage

Lineaments are indicative of zones of localized weathering which are known for high permeability and porosity. Lineaments typically act as conduits for sub-surface movement or accumulation of groundwater. The orientation of the fractures is indicative of the preferential flow path [19, 20]. Such Regions are unsuitable for landfill location. Land areas around a high lineament density zone is avoided, as this may lead to significant contamination of groundwater supplies by leaching. Conversely, areas with low lineament density attract high suitability weightage [2, 12, 21].

Geotechnical considerations also suggest that potential landfill site be far from faults, fissures, joints and shear zones to avoid natural and structural damages [10, 30]. The lineament density (ranging from 0 to 2.31 square km) was reclassified into low, medium and high densities. The lineament density map is presented in Figure 10.

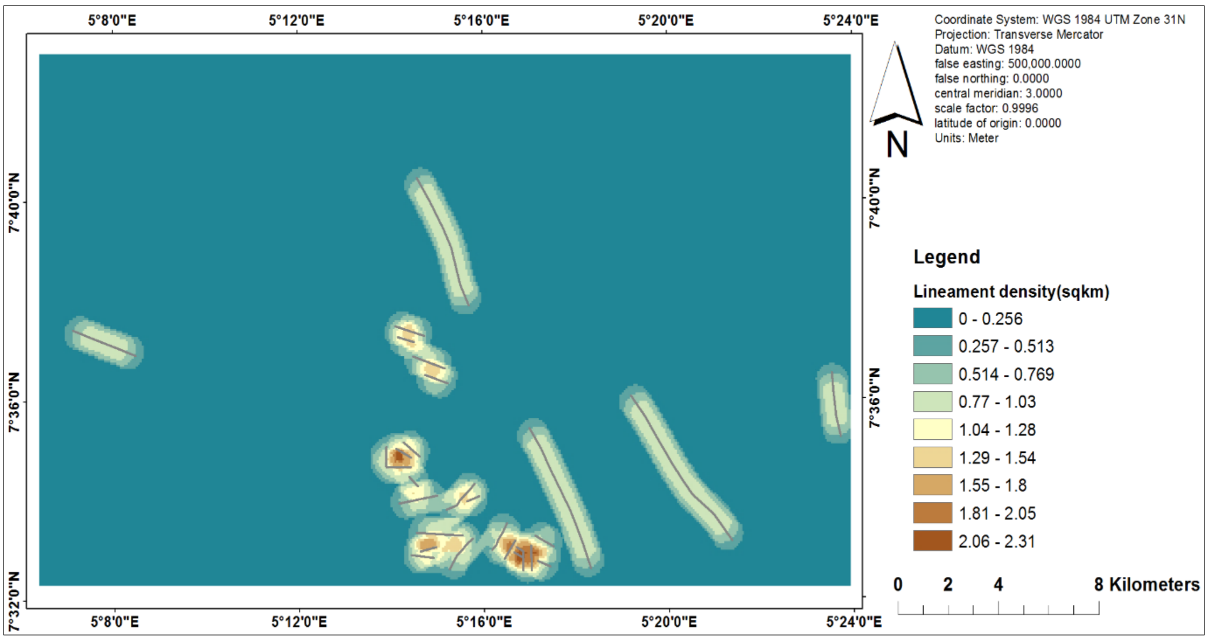

Figure 10. Structure and lineament density of the study area

4.7. Land Use /Land Cover (LULC) Weightage

Vegetation, agricultural land, outcrop, bare ground and urban areas are the most significant LULC classes in the study area (Figure 11). Outcrops and urban areas were considered to be less suitable. The need to protect the aesthetic value of the environment precludes siting landfill in urban areas. Similarly, water bodies are avoided for such activity. Shrub areas indicate high suitability [4, 7, 22].

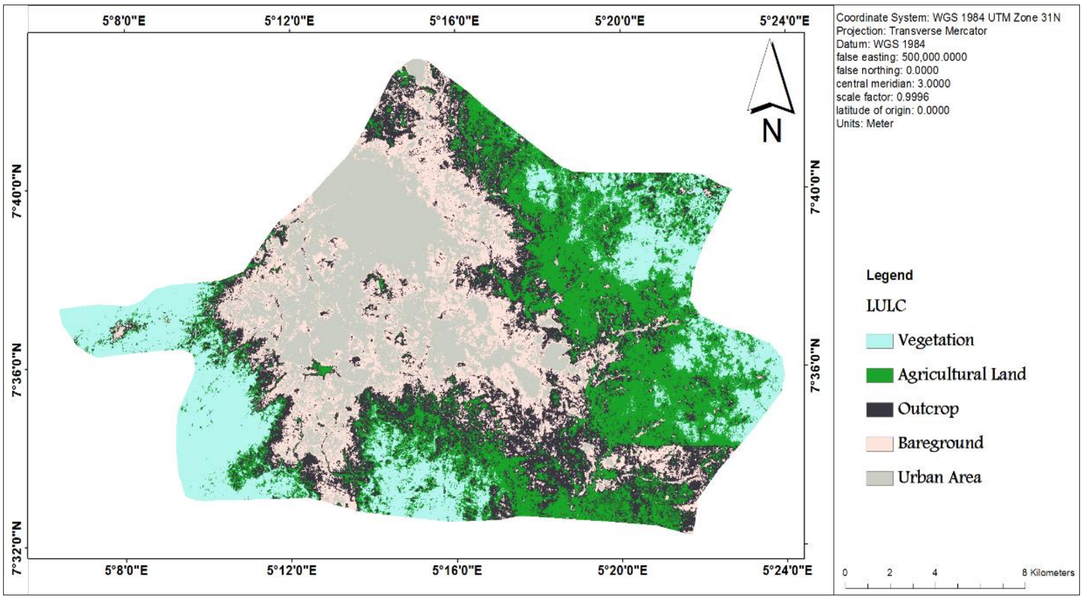

Figure 11. Land use /Land cover map of the study area

4.8. Soil Weightage

The Iwo, Okemesi, and Ondo associations are the three major soil units found in the study area (Figure 12). The soil units are of the residual type, derived from the weathering of the basement crystalline rocks; granites, gneisses, and schists. Clayey soil offers the most suitable medium for the solid waste disposal site on account of its low permeability, which permits the least seepage with appropriate leachate curtailment capacity [31, 32]. Coarse textured soils are generally permeable, while fine textured soils indicate less permeability. Low values of porosity and effective permeability of the soil texture are desirable for landfill siting. The Okemesi association is located on quartz, schists, and gneisses. The soil is composed of very coarse-textured, gravelly, pale grey brown to brown, usually sandy soil. The Iwo soil type is composed of coarse-textured, greyish brown to brown sandy, fairly clayey soils. The Ondo soil unit comprises fine - to medium -textured, orange brown to brownish-red, fairly clayey soils overlying orange, brown, and red mottled clay. Fine grained clayey soil with low permeability, possess high suitability for landfill location with the ability to absorb and retain infiltrating contaminant load. The soil within the area of study was reclassified. Ondo Association has the highest rank of suitability, with Okemesi lowest rank [20, 27].

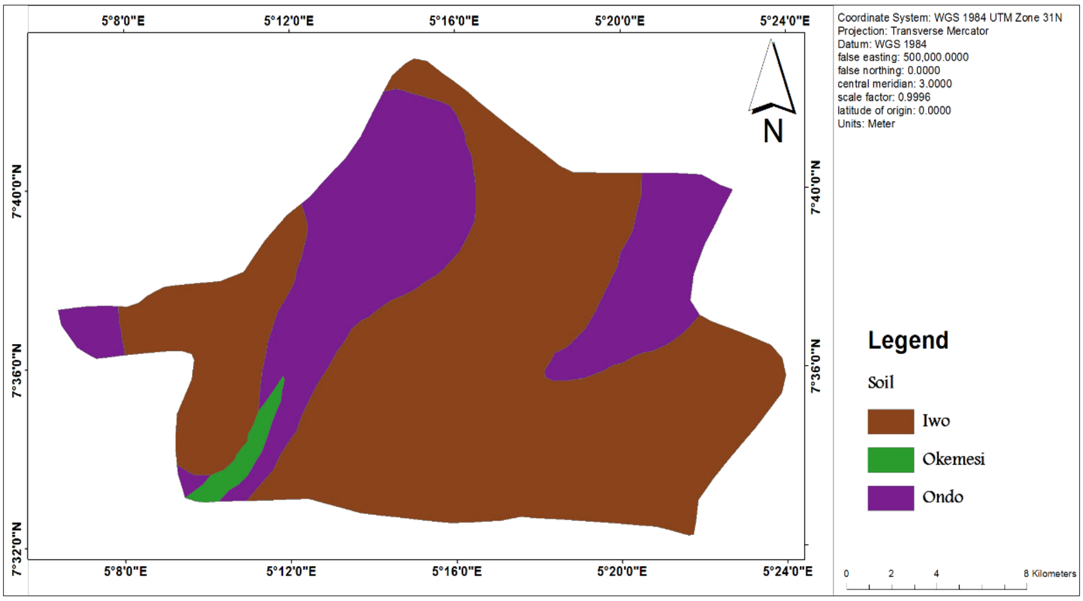

Figure 12. Soil map of the study area

4.9. Overburden Thickness Weightage

Overburden thickness indicates the different degrees of weathering of the rocks around the study area (Figure 13). The overburden encompasses all materials above the presumably fresh bedrock. It is defined as the total depth from the surface to the top of bedrock. This depth is zero where the basement rocks outcrop. The overburden thickness in the study area varies from 1.0 to 79.9 m with a mean of 25.24 m ± 17.2 m [33, 34]. The overburden at the candidate site should be sufficiently thick and of low permeability (clay material). Overburden thickness in excess of 10 m is desirable for a suitable landfill site [27, 31].

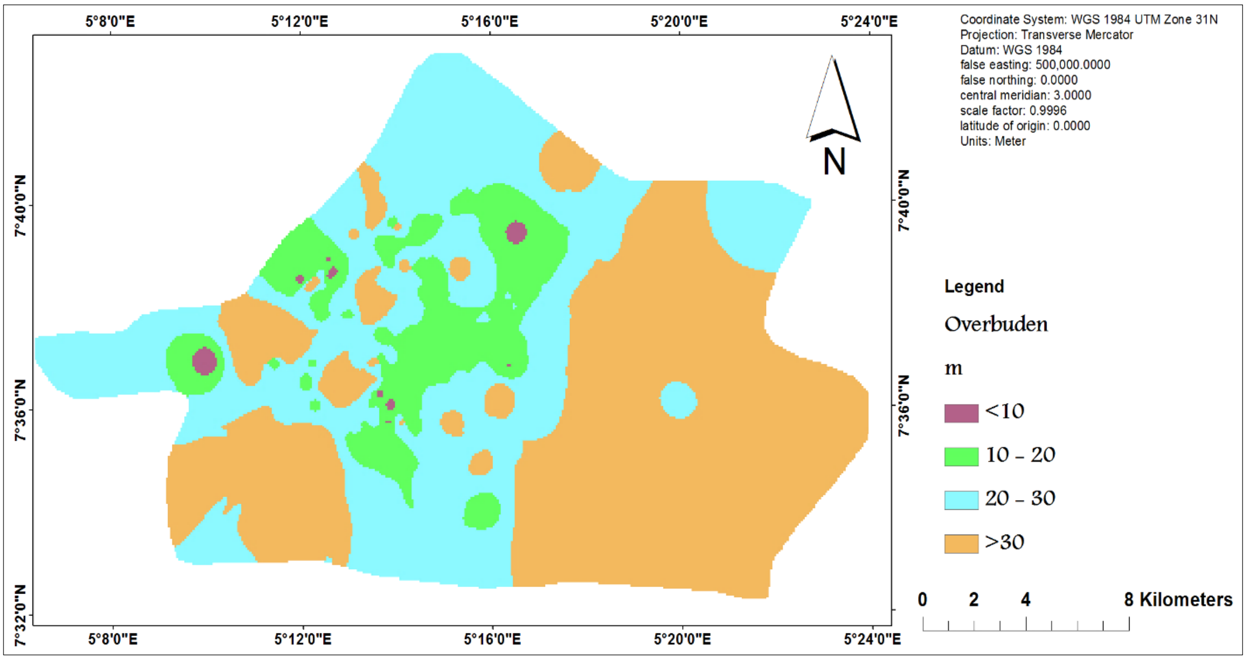

Figure 13. Overburden Thickness map of the study area

4.10. Landfill Suitability Index Map

The outlined methodology produced the landfill suitability index map for the study area (Figure 14). The final index model classified the area into four categories: unsuitable, partly suitable, moderately suitable, and very suitable. The study reveals that 72.1% of the study area is not ideal for landfill location, 21.7% of the area is moderately suitable, whilst only 6.1% is very suitable for landfill siting. This is consistent with findings globally. A shortage of land for waste disposal facilities has been identified as one of the growing problems in most large urban areas [1-3, 5-7, 11-13, 22, 28].

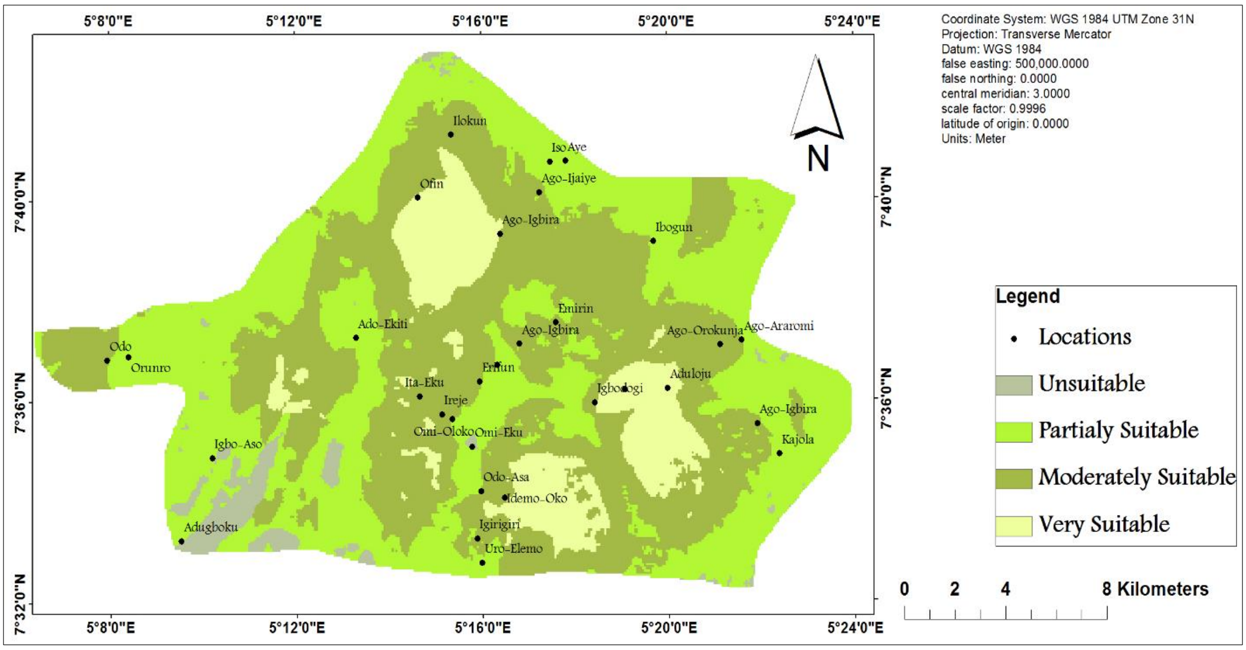

Figure 14. Landfill Suitability Index Map of the study area

Three most appropriate land areas were delineated around Ago Aduloju, Idemo Oko, and Ofin for the establishment of solid waste landfills. Ground-truthing enabled the validation of the locations as largely suitable for landfill siting.

5. Conclusion

Landfill sites in line with scientific and environmental requirements have been delineated in the basement complex of Ado-Ekiti, Southwestern Nigeria. Landfill site selection is a challenging enterprise as it entails consideration of a large number of variables. Conformity with environmental and public health criteria is of utmost concern. The growing city should embrace holistic waste management practices to safeguard the environment and public health. The integration and analysis of various thematic maps and image data proved efficient and effective for the delineation of zones suitable for landfill sites. The selection of landfill sites should be an important component of urban planning with an accent on public health and environmental values.

6. Declarations

6.1. Author Contributions

Conceptualization, A.A. and A.E.; methodology, A.A. and A.E.; software, A.E. and F.O.; validation, A.A., T.O., and O.O.; formal analysis, A.A.; investigation, A.A. and A.E.; resources, F.O., T.O., and O.O.; data curation, A.E.; writing—original draft preparation, A.A. and A.E.; writing—review and editing, A.A., T.O., and O.O.; visualization, F.O. and O.O.; supervision, A.A and O.O. All authors have read and agreed to the published version of the manuscript.

6.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

6.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

6.4. Institutional Review Board Statement

Not applicable.

6.5. Informed Consent Statement

Not applicable.

6.6. Declaration of Competing Interest

The author declares that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

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