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A GEOSPATIAL APPROACH TO MAPPING MUNICIPAL SOLID WASTE DISPOSAL PATTERNS: A CASE STUDY OF UYO METROPOLIS, NIGERIA

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ABSTRACT

Rapid urbanization in Nigerian cities like Uyo Metropolis has exacerbated municipal solid waste (MSW) management challenges, leading to widespread illegal dumping, environmental degradation, and public health risks. This study attempts to simulate waste disposal patterns in Uyo Metropolis of Akwa Ibom State, Nigeria, using geospatial. Sentinel-2 satellite image of 2026 was acquired and processed in Google Earth Engine (GEE) to compute spectral indices. Spatial analyses included distribution mapping, multi-ring buffering (300 m, 500 m, 800 m), Hotspot analysis (1,000 m threshold), and kernel density estimation (1,500 m radius), with overlays on reclassified indices. Results revealed a non-random, road-centric distribution, with dumpsites clustering along key arteries like Ikot Ekpene, Oron, Nwaniba, and Abak Roads, forming linear and nodal patterns in the urban core. The trend reveals solid waste disposal occurring in highly populated areas with heavy concentration of human activities. High-confidence hotspots (95–99%) were concentrated centrally, aligning with high/very high Urban Index classes and high/very high NDBaI bareness zones. These indicate that accessibility, impervious surfaces, and land exposure as key drivers of indiscriminate dumping system. The application of geospatial framework offers a cost-effective tool for prioritizing interventions to mitigate illegal dumping and promote resilient urban planning.

keywords: Municipal Solid waste, Geospatial approach, Waste disposal

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1.0 INTRODUCTION

Solid waste management has become a major challenge in cities of developing countries due to rapid urbanization and population growth. Waste generation has been intensified leading to indiscriminate waste disposal which has further created illegal dumpsites. This menace is not only posing avoidable health problems but also degrading the quality of the environment by distorting environmental stability and development (Mvula et al., 2025, Sawyerr et al., 2017, Ajogwu, and Nwafor 2024, Agbo, 2023, Fraternali, 2024).

The menace of uncontrolled waste disposal is prevalent in Uyo Metropolis of Akwa Ibom State, Nigeria, with its escalating population growth, rapid urbanization and heavy consumption of manufactured products. There is an estimated waste generation rate of 1.34 kg per capita per day (Bassey et al., 2024). Despite efforts by the Akwa Ibom State Environmental Protection and Waste Management Agency, waste management remains inadequate, characterized by irregular collection, reliance on open dumpsites, and proliferation of illegal dumping sites (Udoh, 2016; Mbina, 2015, Usoh et al., 2023, Adedinni et al., 2023). Angaye & Abowei, 2017, Debalke and Admas, 2021) established that such open dumpsites have been linked to bioaerosol pollution, foul odours, and landscape degradation, underscoring the need for systematic monitoring and intervention.

Information on location of municipal solid waste and dump sites can help in planning collection route, clean-up and siting of the most suitable points (Abdullai et al. 2015, Bassey et al., 2024). Several environmental and socio-economic factors need to be considered in achieving sustainable waste management practices. These include the landscape slope, proximity to roads, soil quality, land usage, as well as its relation to human settlements, the livelihoods of the local populace, and the methods employed for waste disposal (Agbara et. al., 2024). Traditional waste management are not sustainable due to insufficient infrastructure, limited funding, and low public awareness, resulting in persistent illegal dumping and inefficient disposal (Abila & Kantola, 2013; Nwosu & Chukwueloka, 2019). Geospatial techniques offer a comprehensive and sustainable solution to these challenges through spatial indices, proximity analysis, and density mapping for dump site identification and assessment (Abdelouhed et al., 2020, Audu et al., 2025; Igwilo, 2024, Zhou et al., 2021, Whiteman et al., 2021, Glanville & Chang, 2015, Karimi & Ng, 2022, Fraternali et. al.,

2024, Nmeregini, C.S., & Igbokwe (2024). This enables precise definition, effective monitoring, and in-depth analysis of the prevailing situation.), and can improve landfill site selection, illegal dumping detection, and environmental risk assessment (Jibril et al., 2022).

Existing studies on waste disposal and management in Uyo have focused on socioeconomic aspects with limited application of advanced geospatial indices and spatial statistics for comprehensive analysis (Ekpo & Bassey, 2020). This research seeks to employ integrated spatial indices (NDVI, NDBI, NDBaI, BSI, UI) and spatial analysis techniques like buffering, hotspot, kernel density analysis to provide empirical evidence and comprehensively map and analyze dump sites within Uyo for sustainable waste management planning.

2.0 STUDY AREA:

Uyo lies approximately on latitudes 4°58'N and 5°04'N and longitudes 7°51'E and 8°01'E. and serves as the capital of Akwa Ibom State in the Niger Delta Region, and South-South geo-political zone of Nigeria. It covers approximately 188 km² within the tropical rainforest belt. The area experiences a tropical monsoon climate with annual rainfall exceeding 2,200 mm and temperatures averaging 26-32°C. The city has witnessed rapid urbanization since 1987 at becoming a State Capital, with high population growth and corresponding expansion of built-up areas at the expense of vegetation and wetlands (Akpan & Udoh, 2021). These characteristics make the area vulnerable to groundwater contamination from leachate migration from improperly sited dump sites (Ekanem et al., 2022).

The topography is predominantly flat to gently undulating, with elevations ranging from 45 to 70 m above sea level, facilitating urban expansion but also exacerbating flooding and leachate spread from dumpsites (Essien & Samimi, 2019). Uyo Metropolis has a population density of over 4,000 persons per square kilometers in core urban zones.

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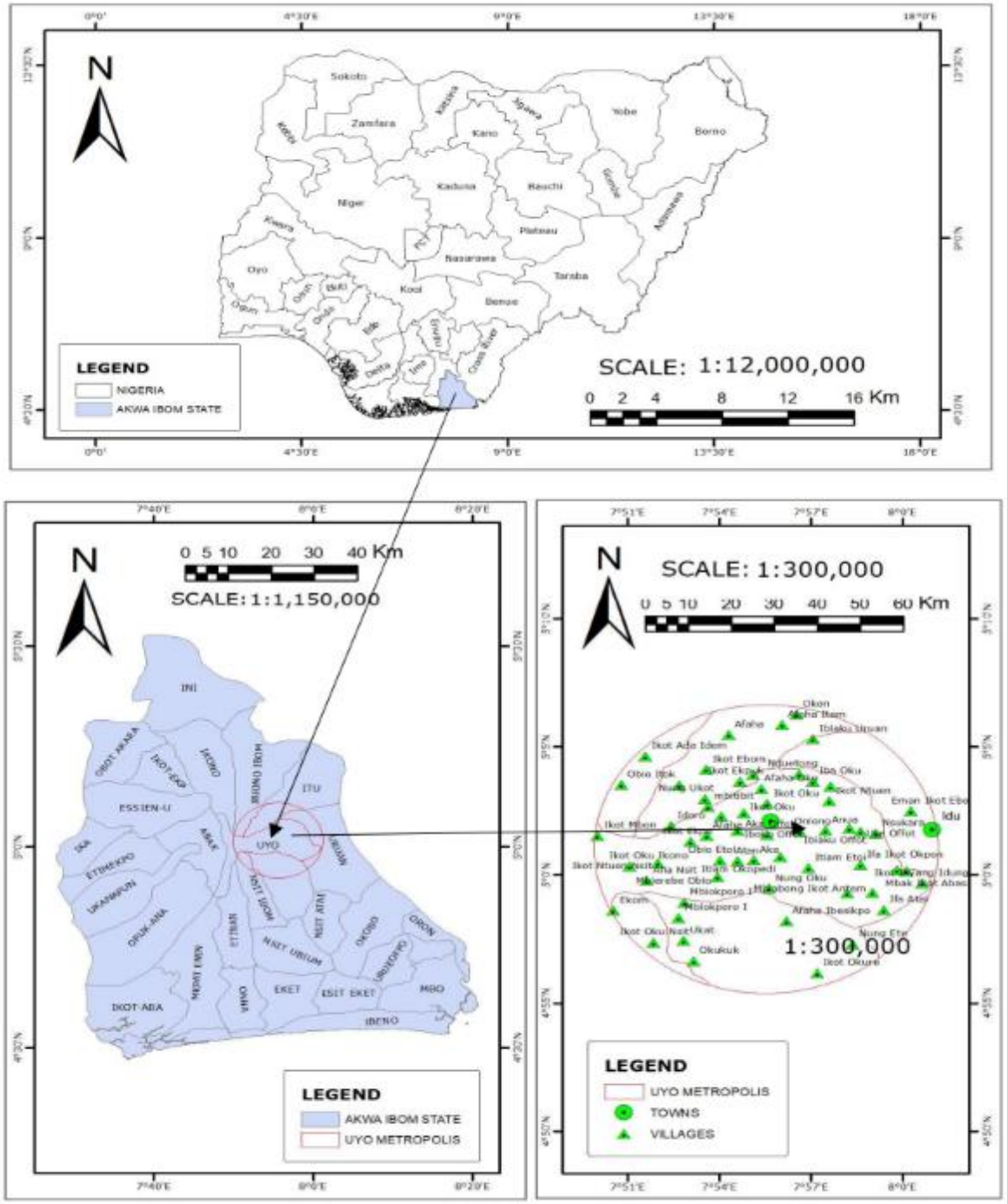

Figure 1: Map of Study Area

3.0 MATERIALS AND METHODS

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The methodology adopted for this study integrated remote sensing, field-based ground truthing, and cloud-based analysis to achieve accurate, cost-effective, and scalable results. Sentinel-2 multi-spectral imagery was acquired and processed in Google Earth Engine (GEE), a cloud-based platform that enables handling of large datasets without local computing limitations. Ground reference data on known dump sites were collected in the field using the open-source mobile application (SW Maps), which facilitated precise GPS point collection with attributes and photos. This hybrid approach combined the strengths of high-resolution satellite data, field validation, and automated classification, making it particularly suitable for urban areas in resource-constrained settings like Akwa-Ibom State.

3.1 FLOWCHART:

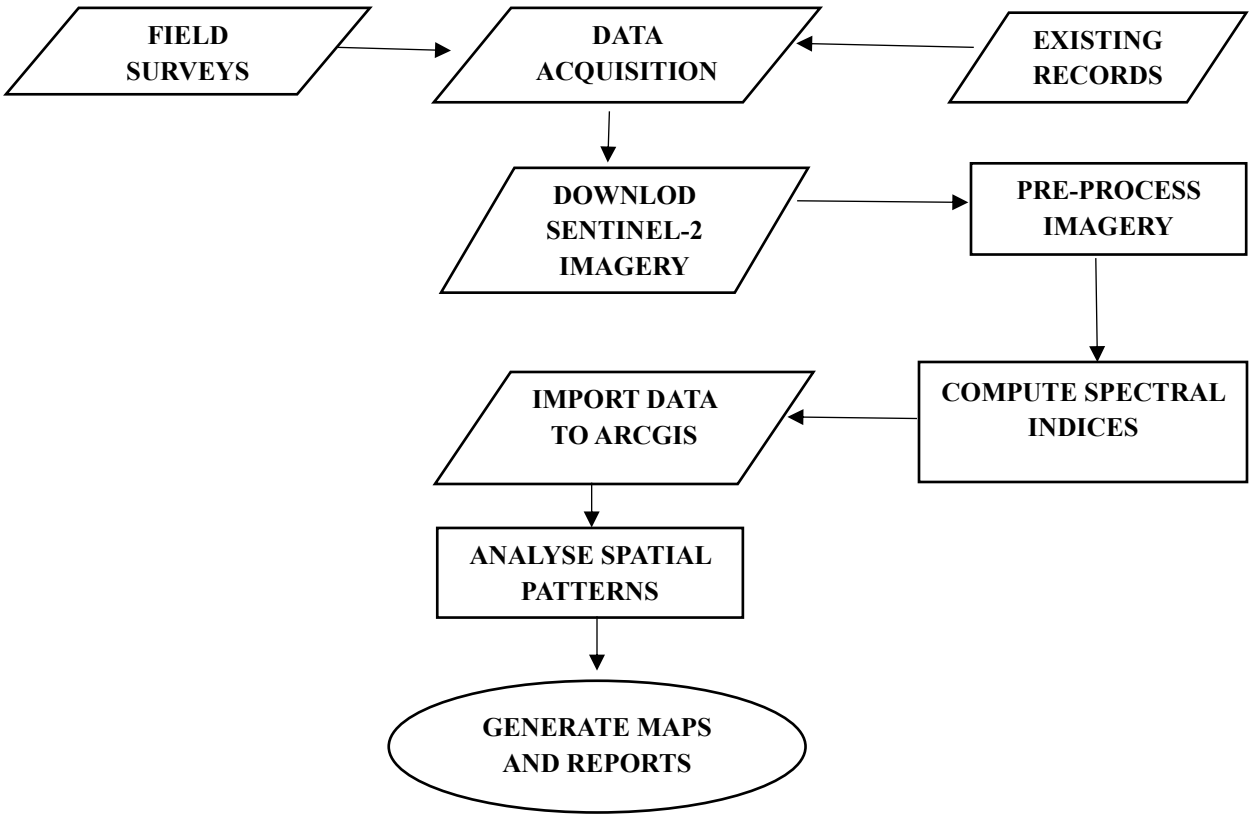

Fig 2: Flowchart for Methodology

3.2 DATA:

The field data was acquired using a mapping-grade mobile application (SW Maps), which is a GNSS-enabled application for collecting the coordinates of points, lines, and polygons. It has the capabilities for absolute positioning and differential positioning. Sentinel-2 imagery with 10m resolution for optical bands acquired from European Space Agency (ESA) through Copernicus Hub, was used. The satellite imagery was in the Geographic Coordinate System (EPSG: 4326), and were projected into WGS 1984/UTM Zone 32N (EPSG: 32632).

3.3 DATA PROCESSING:

Field data collected via SW Maps were exported and subjected to cleaning and quality checks in Microsoft Excel to ensure consistency and accuracy. The cleaned dataset and the road network were then imported into ArcMap 10.8. Image processing was conducted entirely within the Google Earth Engine environment using JavaScript. Geometric correction and initial preprocessing of the study area were performed. Cloud masking and noise reduction were applied. An image collection was filtered by the specified date range, clipped to the study area for further geometric refinement. This was restricted to scenes with cloud cover below a defined threshold, and subjected to cloud masking (lines 20–24). A single image was generated from the available scenes using the median compositing method, and the resulting image was scaled appropriately. Key spectral indices generated included Normalized Difference Vegetation Index (NDVI), Normalized Difference Built-up Index (NDBI), Normalized Difference Bareness Index (NDBaI), Urban Index (UI) and Bare Soil Index (BSI).

Bare Soil Index is a spectral index that combines visible, near-infrared (NIR), and short wave Infrared (SWIR) wavelengths to identify and differentiate bare soil from other land cover types. it is calculated as follows;

BSI = ((SWIR1 + RED) - (NIR + BLUE)) / SWIR1+RED) + (NIR +BLUE)) ….. Equation 1

In this study, Bare Soil Index was applied to identify exposed surfaces by enhancing the reflectance of bare land and suppressing other features.

Normalised Difference Vegetation Index (NDVI) is an indicator in remote sensing used to assess the health of vegetation. NDVI is computed as the difference between near-infrared (NIR) and red (RED) reflectance divided by their sum.

$$NDVI_i = \frac{NIR-RED}{NIR+RED} \quad \ldots\ldots\ldots\ldots \quad \text{Equation 2}$$

where NIR is Near Infra-Red reflectance and RED is red-band reflectance. NDVI values range from **-1 to +1**, with higher values indicating denser and healthier vegetation. NDVI was applied in this study to identify vegetated land from built up areas, and to assess urban expansion and possible impact of urban activities within the study area. This will help in planning and identifying suitable areas for dump sites and green infrastructures.

Urban Index (UI) is used to identify and map built up areas and to assess the spatial extent of urban growth. UI was used to evaluate the effect of urban growth on the proliferation of dumpsites.

$$UI = \frac{SWIR2-NIR}{SWIR2+NIR} \quad \ldots\ldots\ldots \quad \text{Equation 3}$$

where: **SWIR2** = Short-Wave Infrared Band 2, **NIR** = Near-Infrared Band.

Normalized Difference Bareness Index (NDBaI) is used to identify bare land surfaces. An increase in bareness value often indicates environmental deterioration. NDBaI was applied in this study to assess exposed soil surfaces.

The computed index bands were combined into a multi-band image for streamlined export and visualization. Buffering was carried out to generate influence zones around dump sites. The buffers were created at 300-meter radius, 500-meter radius and 800-meter radius). This was done to assess the rate and magnitude of solid waste generation and influence on the environment at various spatial extent. This process produced a new polygon layer consisting of concentric buffer zones surrounding each dump site.

Hot spot analysis was performed to detect statistically significant spatial clusters of dump sites, The output was a new point layer containing z-scores and p-values, identifying significant hot spots (high positive z-scores), cold spots (high negative z-scores), and non-significant locations. Kernel density estimation was applied to generate a continuous surface representing the concentration of dump sites, Overlay maps were produced by combining multiple layers (e.g., kernel density raster over a reclassified index raster, or buffer polygons over the road network) to enable visual comparison of spatial relationships. This approach yielded composite maps that effectively illustrated the spatial relationships between dump site patterns and underlying index or

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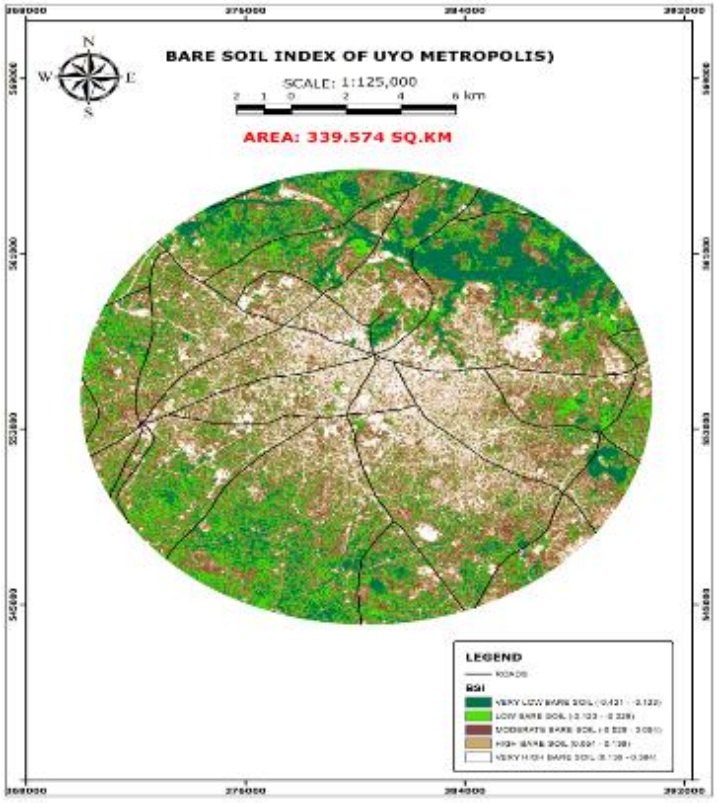
feature layers. Each spectral index raster (NDVI, BSI, UI, NDBI, NDBaI) was reclassified into five classes (Very Low Vegetation, Low Vegetation, Moderate, High, Very High), and an appropriate colour ramp was applied (e.g., green-to-red for NDVI, brown-to-green for built-up/bareness indices).

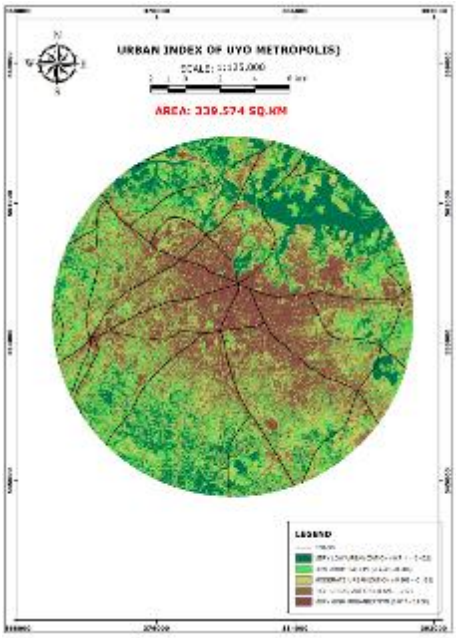
4.0 RESULTS AND DISCUSSIONS



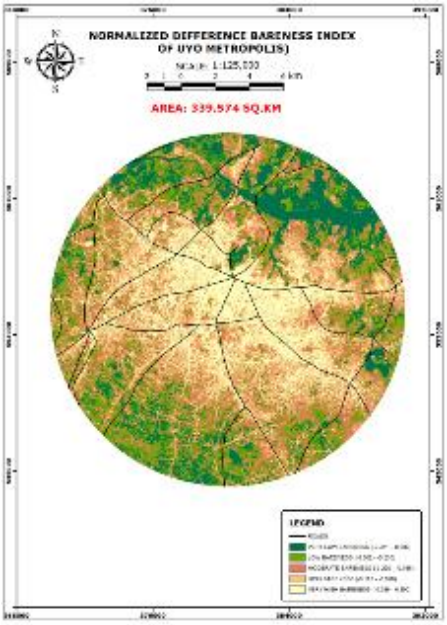
(Figure 3: Bare Soil Index of Study Area)

The result of the Bare Soil Index revealed a high amount of bare soil at the city center and minimal amount of vegetation at the peripherals. The exposed bare surfaces with available road network facilitated illegal dumping sites around these areas, influencing soil and environmental degradation. The Normalized Difference Vegetation Index revealed an absence of vegetative cover except at the outskirt of the city. This resulted from heavy population and increased human activities within Uyo Metropolis. The Urban Index, Normalized Difference Built-up Index and Normalized Difference Bareness Index all revealed high urban and built-up areas as having

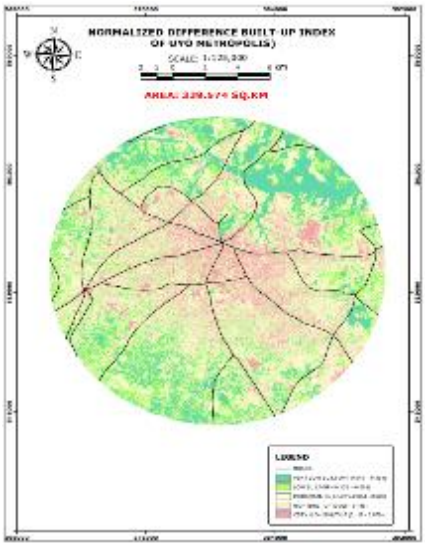
numerous illegal dump sites. It was observed that proximity to authorized waste disposal points significantly influenced the illicit trend prevalent in the central part of Uyo Metropolis.



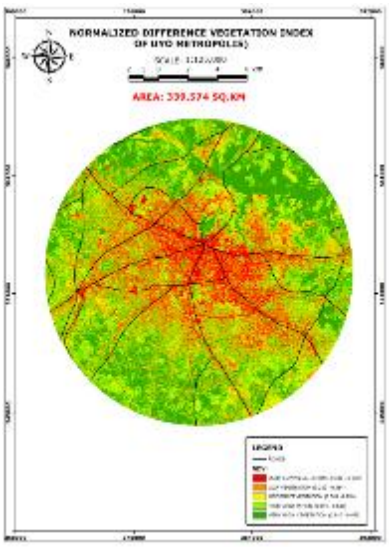
(Fig 4: Urban Index of Dumpsites)



(Fig 5: Normalized Difference Bareness Index)



(Fig 6: Normalized Difference Built-up Index)



(Fig 7: Normalized Difference Vegetation Index)

4.1 KERNEL DENSITY OF DUMP SITES OVERLAID ON NDBI BUILT UP CLASSES

The Kernel Density of Dump Sites overlaid on NDBI Built-up Classes map in Figure 8 indicates that indiscriminate waste disposal occurs in highly populated areas with heavy human activities

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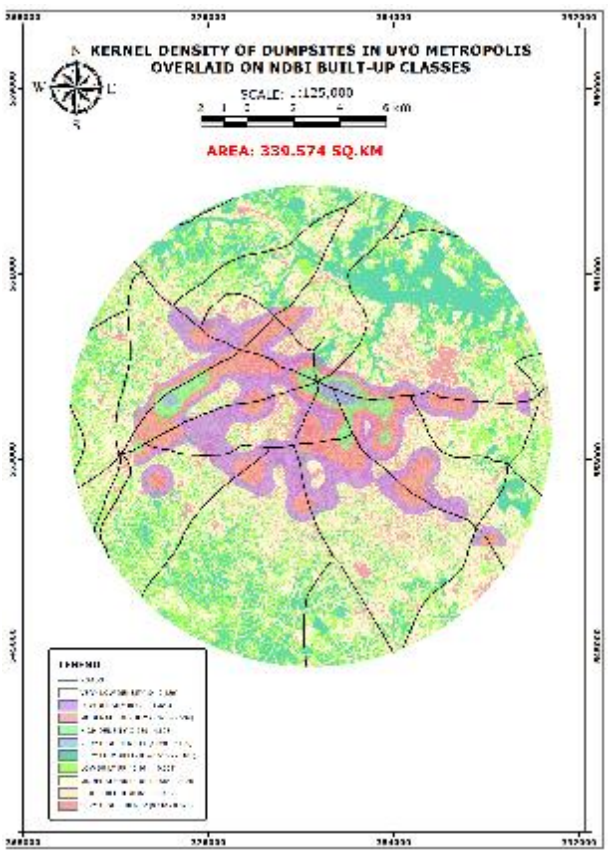
where large volume of waste is generated. The case here is indicative that land management practices may not be sufficient to address the challenges of solid waste disposal within the study area. Land use zoning, delayed reclamation efforts and other environmental protection practices may be lacking, leaving certain parcels undeveloped and vulnerable.



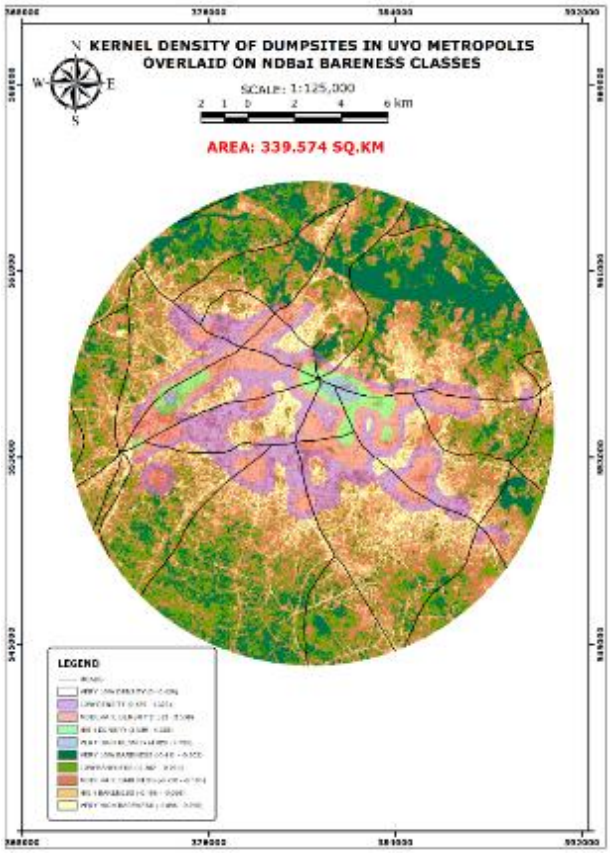


Figure 8:(Kernel Density Overlaid on NDBI Map), *(Figure 9: Kernel Density of Dump Sites overlaid on NDBaI Bareness Classes)*

4.3 Kernel Density of Dump Sites Overlaid on NDBaI Bareness Classes

The kernel density surface, when superimposed on the reclassified Normalized Difference Bareness Index (NDBaI) classes, unveiled a striking and pronounced aggregation of dump sites within territories designated as high to very high bareness and this is particularly evident along road corridors and the fringes between urban and rural areas. These bare surfaces having little or no vegetative cover, minimal soil stability, and scarcity of natural or artificial structures have become vulnerable to waste disposal. This may be attributed to their enhanced visibility from passing traffic, unimpeded physical access, and absence of alternative land utilization that might otherwise deter such activities.

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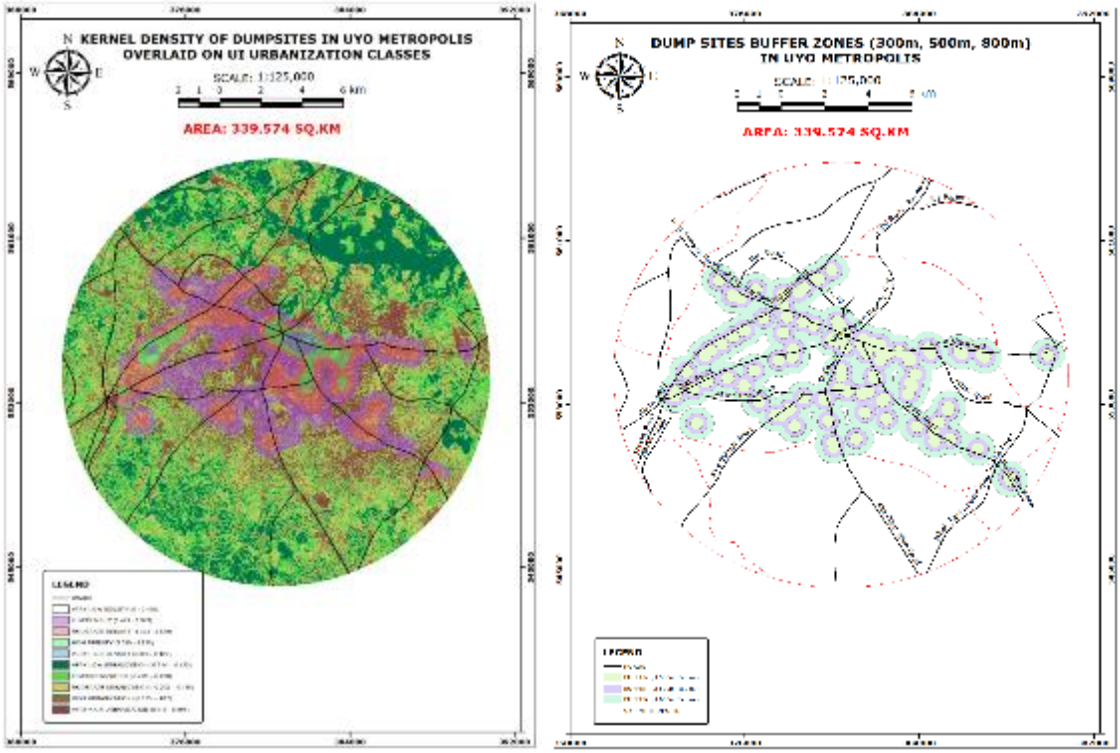

(Figure 10: Kernel Density of Dump Sites Overlaid on UI Urbanization Classes), (Figure 11: Buffer Zone)

4.5 Kernel Density of Dump Sites Overlaid on UI Urbanization Classes

The overlay of the kernel density estimation for dump sites on the reclassified Urban Index (UI) classes reveals a high dump concentration in regions categorized as high to very high urbanization. These zones, which are prominently situated within the heart of Uyo Metropolis consist of intense urban development, including extensive impervious surfaces such as concrete pavements, commercial buildings, and residential complexes. This development suggests that dump sites are not relegated to the outskirts or peripheries but proliferate within the most active and populated sectors of the city. This further implies that the rapid pace of urbanization far outweighs the existing structure to cater for proper waste disposal systems. There is an urgent need for integrated planning strategies that prioritize waste management scheme in high-urbanization zones, in order to mitigate the long-term consequences of such menace on community well-being and urban resilience.

4.6 DUMP SITES BUFFER ZONES (300m, 500m, 800m)

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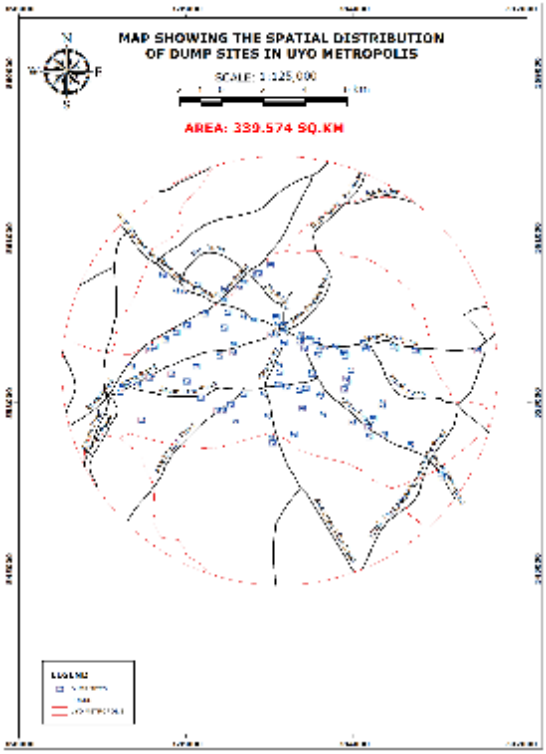
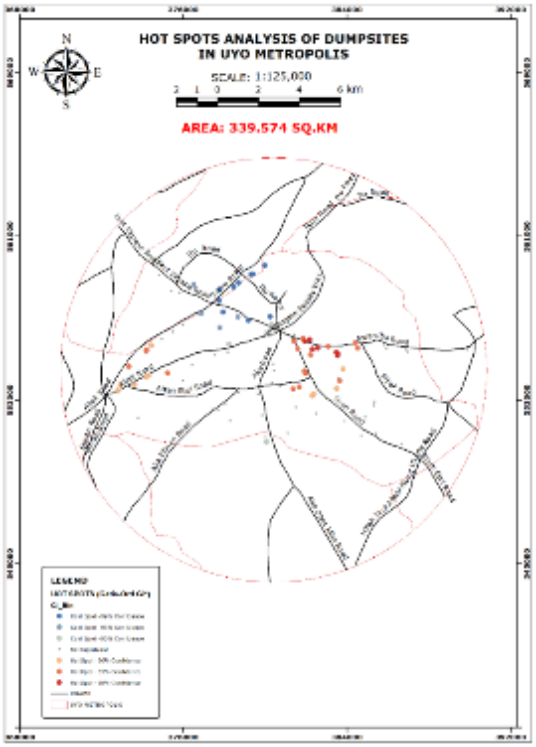
Figure 10 represents location of dump sites within the study area and the impacts on nearby and surrounding facilities. Buffers were created at 300m, 500m, and 800m. The 300m radius revealed a trend of illegal dump concentration along Ikot Ekpene Road and Oron Road. The 500m and 800m radius cover large parts of residential and business areas in the city center and extends toward the west. a large number of residential, educational, commercial and public facilities suffer the risk of this indiscriminate dump system.

4.7 SPATIAL DISTRIBUTION OF DUMP SITES:





(Figure 12: Spatial Distribution of Dumpsites in Uyo Metropolis), (Figure 13: Hotspot Analyss of Dumpsites in Uyo Metropolis)

The spatial distribution map of field-verified dump sites across Uyo Metropolis reveals a pronounced non-random pattern, characterized by a strong alignment with the primary road infrastructure. Sites are densely grouped along key radial routes (such as Ikot Ekpene Road, Oron Road, and Abak Road) and major connectors like Wellington Bassey Way, forming elongated linear clusters and nodal concentrations at prominent intersections. In contrast, the outer and less accessible peripheral zones show few or no recorded dump locations. The map further reveals a

heavy cluster within the city center and extending to the outskirts indicating that more waste is generated in the heavily populated and urbanized areas. This trend shows that residents discard their waste where it is most convenient and with a minimal cost in terms of travelling and without consideration to health and environmental impact.

4.8 HOT SPOTS ANALYSIS OF DUMP SITES

The hot spot analysis identifies statistically significant clusters of dump sites, with high-confidence hot spots (95–99%) concentrated mainly in the central part of the metropolis, particularly along the intersection of major roads such as Nwaniba Road, Wellington Bassey Way, Ikot Ekpene Road, and Oron Road. Cold spots (low-confidence clusters) are more scattered toward the periphery, while non-significant areas dominate the outer zones. The presence of strong hot spots in the urban core implies that dump sites are not randomly distributed but exhibit spatial autocorrelation, forming persistent problem areas where dumping is concentrated and self-reinforcing. The significance of this pattern lies in the evidence of localized hotspots of waste mismanagement, likely driven by population density, road accessibility, and limited formal disposal options in these central zones. This clustering pattern points to an inefficient waste collection system.

5.0 CONCLUSION

This work successfully mapped and analyzed dump sites in Uyo Metropolis using geo-spatial techniques. It demonstrated the efficacy of Sentinel-2 data and GEE in detecting waste patterns offering a scalable, cost-effective alternative to traditional surveys in resource-limited settings. By quantifying spatial clustering and proximity risks, the study provides evidence-based tools for urban planners to prioritize intervention strategies.

The field data, gathered over three days using SW Maps, revealed 116 dump sites unevenly spread through the entire study area. Key findings indicate that dump sites in Uyo are unevenly distributed, predominantly clustered along major road networks such as Ikot Ekpene Road, Oron Road, Nwaniba Road, and Abak Road, forming linear patterns at intersections and corridors. This road-aligned concentration shows accessibility as a primary driver of illegal dumping, turning transport routes into informal disposal zones. Spectral indices like the Normalized Difference

Vegetation Index (NDVI), Normalized Difference Built-up Index (NDBI), Normalized Difference Bareness Index (NDBaI), Urban Index (UI) and Bare Soil Index (BSI) highlighted high built-up and bare soil areas in the urban core and transitional zones, where dump density is remarkably high. Kernel density overlays confirmed that high waste concentrations occur in densely developed and exposed soil areas, establishing urbanization and land use facilitate and sustain dumping trend. Buffer analysis further revealed that substantial portions of residential, commercial, and road infrastructure fall within 300-800 m influence zones of dump sites, exposing populations to health risks arising from leachate, air pollution, and vector-borne diseases. This road-aligned pattern underscores accessibility as a primary driver of dumping, with sites forming linear and nodal clusters in the urban core.

In conclusion, the proliferation of dump sites in Uyo Metropolis reflects inadequate effort in Solid Waste Management amplified by urban expansion and poor regulation. Recommendations include enhancing waste collection along high-density corridors, implementing GIS-based monitoring for real-time enforcement, and community education to curb illegal dumping.

The significance of this work is in its contribution to evidence-based waste management. By mapping dump hotspots and their spectral associations, the study provides a framework for prioritizing interventions, such as enhanced monitoring along key corridors and integration of geospatial tools into local policies.

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