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Geospatial Assessment of Waste Disposal Site's Impact on Air Quality in Sokoto Metropolis, Nigeria

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Abstract

Rapid urban expansion and inadequate waste management in northern Nigerian cities have increased open dumping and burning of waste. This is contributing significantly to air pollution and related health risks in the region. This study assessed the impact of waste disposal sites on air quality in Sokoto metropolis using a geospatial analytical approach. Forty-nine (49) active waste disposal sites were identified and mapped. Air quality parameters, including particulate matter ($PM_{2.5}$ and PM_{10}) were analyzed. Secondary datasets included administrative boundaries from the Office of the Surveyor General of the Federation, road and water body data from OpenStreetMap, and population data from WorldPop. The data were processed and analysed in ArcGIS 10.8. The results show that distribution of waste disposal site were clustered in the central and north-eastern areas of the metropolis (ratio = 0.818, z = –2.438, p = 0.015). Air quality results showed elevated particulate matter levels around several waste disposal sites, with concentrations decreasing with distance from the sites. Hazard zonation maps generated through Multi-Criteria Decision Analysis (MCDA) indicated predominantly moderate-risk zones, with localised high-risk areas near active waste disposal sites. Population overlay analysis revealed that about 90% of residents in the metropolis live in moderate to high exposure zones. The findings demonstrate that waste disposal practices contribute to localised air quality degradation and increased environmental risk. The study recommends improved waste management systems, enforcement of buffer regulations, and adoption of GIS-based planning to support sustainable urban environmental management.

Keywords: *Waste disposal sites, air quality, spatial interpolation method, population exposure, Sokoto Metropolis*

Résumé

L'expansion urbaine rapide et la gestion inadéquate des déchets dans les villes du nord du Nigéria ont accrue les dépotoirs et les incinérations à ciel ouvert. Ce phénomène contribue significativement à la pollution atmosphérique et aux risques sanitaires associés dans la région. L'objectif de cette étude est d'évaluer l'impact des sites d'élimination des déchets sur la qualité de l'air dans la métropole de Sokoto à l'aide d'une approche géospatiale. Quarante-neuf (49) sites de déchets actifs ont été identifiés et cartographiés. Les paramètres de qualité de l'air, notamment les particules fines ($PM_{2.5}$ et PM_{10}), ont été analysés. Les données secondaires utilisées comprenaient les limites administratives du bureau du géomètre général de la Fédération, les données routières et hydrologiques d'OpenStreetMap et les données démographiques de World Pop. Les données ont été traitées et analysées avec ArcGIS 10.8. Les résultats montrent que les sites d'élimination des déchets sont concentrés dans les zones centrales et nord-est de la métropole (ratio = 0,818, z = -2,438, p = 0,015). Les résultats concernant la qualité de l'air ont révélé des niveaux élevés de particules fines autour de plusieurs sites d'élimination des déchets, la diminution des concentrations avec la distance. La carte de zone à risque générées par une analyse multicritères (AMCD), a indiqué des zones à risque modéré prédominantes, avec des zones à haut risque localisées à proximité des sites d'élimination des déchets en activité. L'analyse de la population a révélé qu'environ 90 % des habitants de la métropole vivent dans des zones d'exposition modérée et élevée. Ces résultats démontrent que les pratiques d'élimination des déchets contribuent à la dégradation localisée de la qualité de l'air et à l'augmentation des risques environnementaux. L'étude recommande l'amélioration des systèmes de gestion des déchets, le renforcement de la réglementation relative aux zones tampons et l'adoption d'une planification basée sur les SIG pour soutenir une gestion environnementale urbaine durable.

Mots-clés: Sites d'élimination des déchets, qualité de l'air, interpolation spatiale, exposition de la population, métropole de Sokoto.

1.0 Introduction

Solid waste typically refers to any matter or material discarded by people that cannot be used by the person or people who first generated it. This includes household garbage, refuse, and other wastes discharged by domestic, industrial, institutional, commercial, and community sources. Solid waste can be found in either solid, semi-solid, or gaseous state. (WHO & US, EPA, 2025) Solid waste has become an issue of international environmental and health importance in the contemporary world. The increase in solid waste generation worldwide is attributed to growing population, rapid economic development, rising living standards, and outbreaks of diseases (Shabani *et al*., 2023). Management of solid waste typically involves storage, collection, conveyance, treatment, disposal, monitoring of disposal sites, and the inclusion of waste reduction and prevention strategies. Improper disposal of solid waste impacts the environment in many ways, including pollution of air, water, and soil, and it also accelerates the spread of diseases (Nanda and Berruti 2021; Shabani *et al.,* 2023). Solid waste comprises various complex hazardous and non-hazardous components and fractions that can exacerbate environmental health issues. The environmental and social impacts due to disposal and management of solid waste are a cause of concern in terms of human well-being and environment's safety (Guerrero *et al.,* 2013). Spatial aspect of waste management has become more significant in environmental research. A Geographic Information Systems (GIS) analysis is effective for analysing the spatial distribution of dumpsites and their environmental impacts, as is remote sensing. Dumpsites emit different air pollutants like methane (CH_4), carbon dioxide (CO_2), volatile organic compounds (VOCs), and particulate matter (PM_{10} and $PM_{2.5}$) that are hazardous. The most serious threats to human health (Mustaphar *et al*., 2025).

The World Bank (2022) states that poor sanitation and waste management adds to local pollution and global greenhouse gas emissions. Lack of sufficient solid waste management systems in Nigeria is responsible for the emergence of illegal disposal sites in urban areas (Ichipi & Senekane, 2023). This is due to inadequate urban planning, inadequate waste collection infrastructure, and lack of enforcement of environmental regulations (Abila & Kantola, 2013). In the urban areas, such as Sokoto, where landfill wastes are scarce, the methods of waste disposal include open dumping or burning of waste materials which has a significant impact on the air quality (Abubakar *et al*., 2022).

The core research problem addressed in this study is that Sokoto Metropolis faces significant issues due to its reliance on open disposal sites as the primary method of waste management, with many residents resorting to uncontrolled waste dumping that results in soil, air, and water pollution (Sarkingobir *et al*., 2023). To address this problem, this study aims at investigating the impact of waste disposal sites on air quality in Sokoto Metropolis, using geospatial analytical techniques. The specific objectives are to: i) examine the spatial distribution of waste disposal sites, ii) assess air quality conditions around these sites, and iii) evaluate the exposure risk to surrounding communities.

2.0 Materials and Methods

2.1 Study Area Description

Sokoto Metropolis, the administrative capital of Sokoto State in northwestern Nigeria, is geographically defined by the coordinate pairs (latitude, longitude). 13°02′00″N, 5°09′00″E and 13°09′00″N, 5°15′00″E. The metropolis is bordered by Wamakko Local Government Area to the north and west, Dange-Shuni to the south, and Kware to the east. It is located within the semi-arid Sudan savanna ecological zone, which is characterised by persistently high temperatures, low and highly variable annual rainfall, and well-defined wet and dry seasons

(Olofin,2008; NiMet,2022).

Sokoto, situated in Nigeria's north-western part, experiences hot semi-arid (BSh) weather found in the Sahelian region. This weather exhibits very marked seasonal changes in both temperatures and precipitation levels (NearWeather, 2024). Sokoto's average annual temperature is around 28.3 °C, though daily temperature levels from February through April often go above 40 °C, even touching 45 °C sometimes (Abaje *et al.,* 2022; NearWeather, 2024). The rainy season in Sokoto is brief and moderate, usually spanning June to September, with rainfall peaking in July and August**.** Unlike tropical climates, showers in Sokoto are less intense and more sporadic. Annual rainfall ranges from 500 mm in the northern parts to over 800 mm in the southern parts of the state (Abaje *et al*., 2022 & Bala *et al*., 2022; WhatstheWeather, 2024).

From October or November to February, the dry season is marked by the presence of the Harmattan dry, dust-laden winds blowing from the Sahara. These winds reduce visibility, lower relative humidity, and can lead to lower daytime temperatures, particularly in the early mornings and evenings (Bala *et al*., 2022 & Abaje *et al*., 2022).

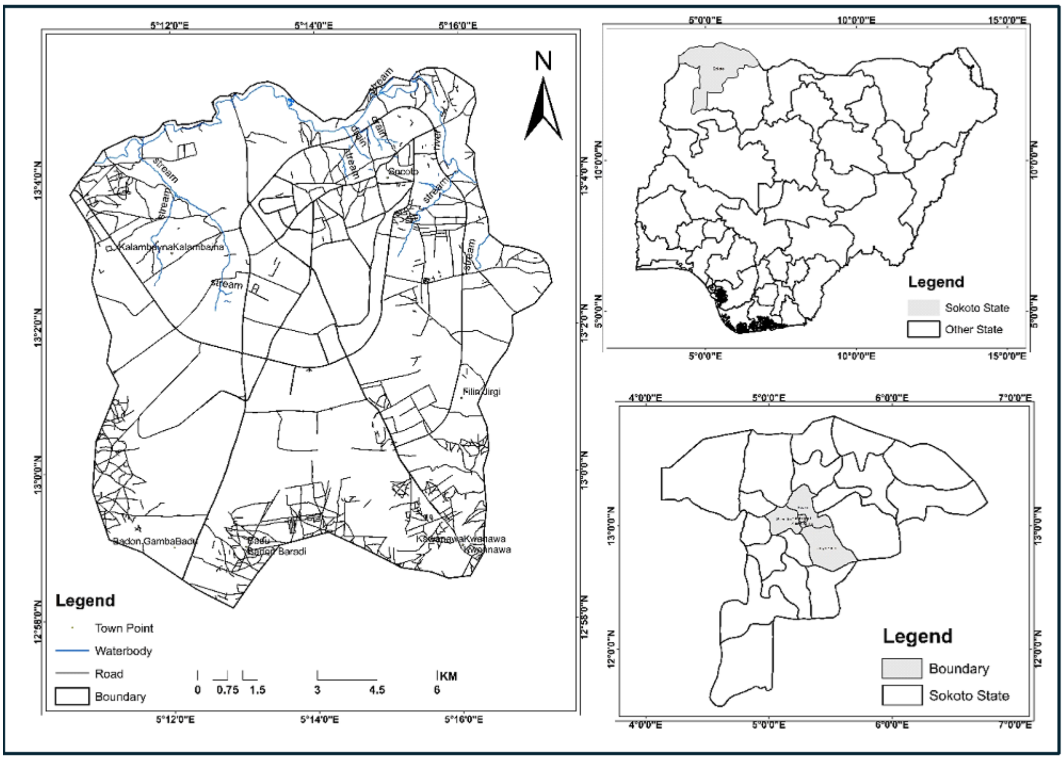

Figure 1: The Study Area

2.2 Data and Sources

The coordinates of identified waste disposal sites were obtained through a field survey using a handheld Global Positioning System (HGPS) receiver. The use of GPS for field data acquisition is widely recognised in geospatial research due to its ability to provide accurate, real-time positional information for mapping environmental features (United States Geological Survey, 2020; Environmental Systems Research Institute, 2023). The coordinates were recorded in the Universal Transverse Mercator (UTM) projection, which is commonly used in spatial analysis because it preserves distance and area measurements, making it suitable for local- and regional-scale studies (ESRI, 2023).

Air quality measurements were collected at selected waste disposal sites using a portable monitoring instrument, a handheld Temtop device. The parameters measured were particulate matter ($PM_{2.5}$ and PM_{10}), which are widely used indicators of urban air pollution and associated health risks (WHO, 2021; Kumar *et al.,* 2020). Measurements were taken at a single sampling point located approximately 10–20 m from each dumpsite, depending on site accessibility and safety, and efforts were made to maintain consistency across all locations. Readings were recorded at a standard height of about 1.5–2 m above ground level, representing human breathing height. The spatial datasets used in this study were obtained from a combination of authoritative and open-source platforms and integrated within a GIS environment to support comprehensive spatial analysis.

The administrative boundary of Sokoto Metropolis was sourced from the Office of the Surveyor General of the Federation, ensuring an accurate delineation of the study area for mapping and spatial operations. Additional spatial layers, including road networks, residential areas, and water bodies, were derived from OpenStreetMap, while population distribution data were obtained from WorldPop. These datasets were integrated to perform proximity, buffer, and overlay analyses, enabling the assessment of spatial relationships between waste disposal sites, environmental features, and exposed populations. OpenStreetMap has become a widely accepted source of geospatial data, particularly in data-scarce regions, due to its extensive coverage and frequent updates (Boeing, 2020; Herfort *et al*., 2021). Studies indicate that OSM data, especially road networks, can achieve high levels of completeness (often above 80-90%) in urban areas (Herfort *et al*., 2019; Boeing, 2020).

3.0 Data Processing

All datasets were processed and analysed within the ArcGIS 10.8 environment, which provides an integrated platform for spatial data management, analysis, and visualisation. Spatial pattern analysis of waste disposal sites was conducted using the Average Nearest Neighbor (ANN) statistical tool, which evaluates spatial distribution by comparing the observed mean distance between points with the expected mean distance under a random distribution. The resulting nearest neighbor ratio, z-score, and p-value were used to determine whether the pattern is clustered, random, or dispersed. This method is widely applied in spatial and environmental studies for detecting patterns and supporting planning decisions (O'Sullivan & Unwin, 2010).

Spatial interpolation of air pollutant concentrations was conducted using the Inverse Distance Weighting (IDW) method to generate continuous surface maps of air quality across the study area. While geostatistical techniques such as kriging are often preferred for their ability to model spatial autocorrelation and quantify prediction uncertainty, they require sufficiently dense and well-distributed sampling points to produce reliable variograms (Li & Heap, 2021). In this study, the limited number and uneven distribution of sampling locations constrained the effective application of kriging. IDW was therefore adopted due to its simplicity, computational efficiency, and suitability for sparse datasets. The method assumes that observations closer in space exert greater influence on predicted values, which aligns with the localised dispersion patterns of pollutants around waste disposal sites. Recent studies indicate that IDW performs comparably to kriging under conditions of limited or irregular sampling, particularly in air quality and environmental assessments (Yao *et al.,* 2019; Chen *et al.,* 2022). Moreover, IDW remains widely used in GIS-based studies in data-constrained environments, providing reliable and interpretable outputs for spatial decision-making (Li *et al*., 2020).

Hazard zonation was developed using a Multi-Criteria Decision Analysis (MCDA) framework that integrated pollutant concentrations and population density as key variables. Pollutant concentrations ($PM_{2.5}$ and PM_{10}) were used to represent the intensity and spatial distribution of environmental hazards because of their strong associations with adverse health outcomes (WHO, 2021). while population density was included to capture the human dimension of risk, recognising that exposure depends on both hazard levels and the number of people affected (Gorjian *et al*., 2023; Chen *et al*., 2021). Population exposure was subsequently quantified by overlaying hazard zones with gridded population data from WorldPop, enabling estimation of the number of residents within each risk category. This GIS-based approach supports spatially explicit exposure assessment and has been widely validated for identifying vulnerable populations and informing public health interventions (Stevens *et al.,* 2020).

4.0 Results and Discussions

The spatial distribution of waste disposal sites within Sokoto Metropolis is clearly presented in Figure 2. It is clear that there is an uneven distribution of these sites, with a relatively large concentration of waste disposal sites found in central and northeastern regions, especially in residential locations and along road networks, compared to relatively small numbers in outlying regions. These findings are similar to previous studies on waste distribution patterns, which have found that waste dumping sites tend to cluster in easily accessible areas that experience high socio-economic activities. This finding is further strengthened by the statistical result from the Average Nearest Neighbour (ANN), $R_n = 0.818$, $z = -2.438$, $p < 0.05$. The result reveals that there is an unusual cluster formation for waste disposal sites and not a random spatial distribution as previously expected. Socio-economic activities and transportation accessibility are very important factors that determine the location of waste disposal sites.

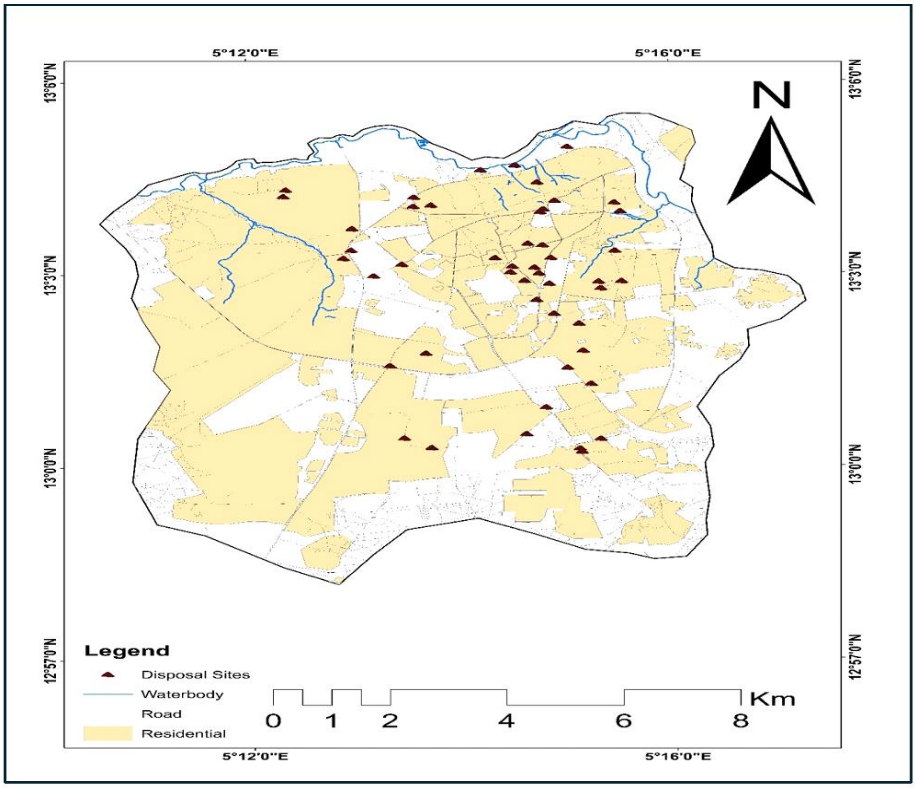

Figure 2: Spatial Distribution of Identified Waste Disposal Sites

From the outputs of the ANN analysis (Table 4.1), it was found that the R_n value stood at 0.8179, and the z-score amounted to -2.4377 with a p-value of 0.0147. These findings are well within the "Clustered" range, as shown in the conceptual framework of nearest neighbor statistics (Figure 2).

In the field of spatial statistics, a clustering pattern (R < 1 and statistically significant z-score) suggests that the location of features is closer than expected when compared to the CSR model (O'Sullivan *et al.,* 2010). The z-score being -2.44 indicates that the probability of this pattern being the result of random processes is lower than 5%. This finding is supported graphically by the Kernel Density map (Figure 4) depicting clustering of the waste facilities within the central and eastern parts of the city. Table 4.1: Results of Average Nearest Neighbor Analysis

Table 1: Results of Average Nearest Neighbor Analysis

Observed Mean Distance:	399.30 m
Expected Mean Distance:	488.17 m
Nearest Neighbor Ratio:	0.82
z-score:	-2.44
p-value:	0.01

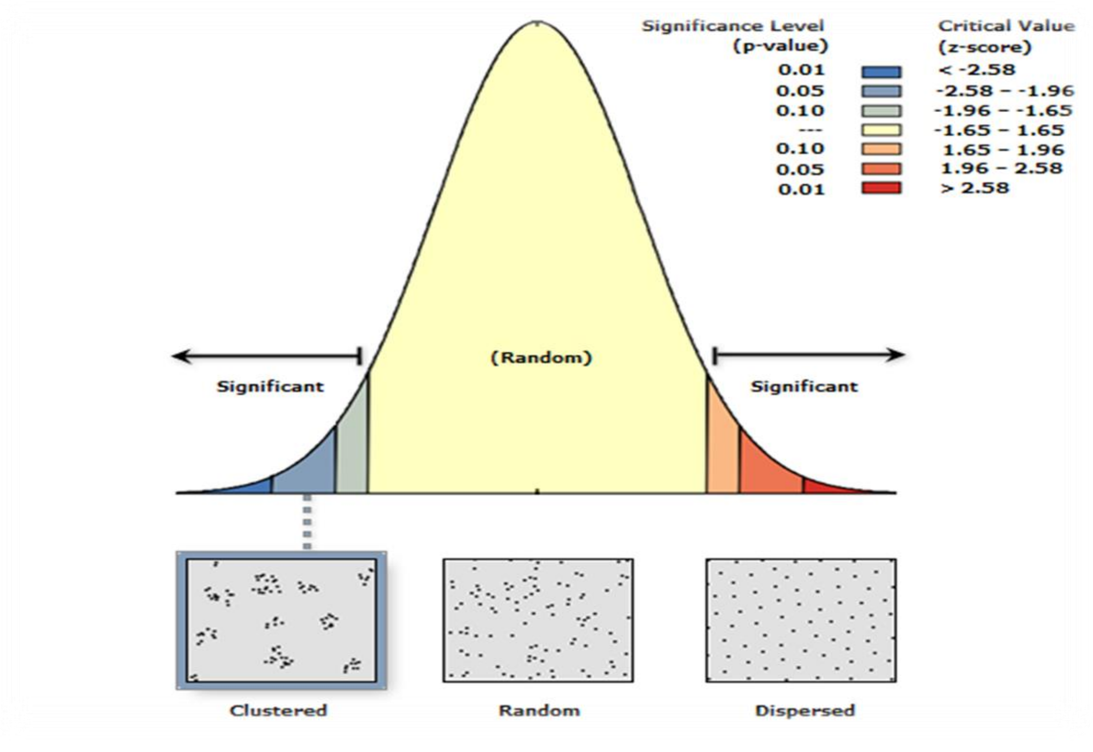

Figure 3: Average Nearest Neighbor summary

Kernel density estimation (KDE) technique was employed to determine high-intensity areas of disposal sites. Figure 4 shows that the center-eastern region of Sokoto Metropolis has high and very high density, which implies the existence of hotspots where waste dumping takes place. Low-density zones exist at the margins, implying limited dumping activities in such zones. KDE is commonly used in environmental

GIS to locate hotspots and determine intensity surface of any phenomena (O'Sullivan *et al.*, 2010). It is evident that the occurrence of hotspots has been influenced by urban density and socio-economic activities, and this phenomenon agrees with what is globally observed, since informal waste dumping usually occurs in zones lacking adequate municipal waste management facilities (Hoornweg & Bhada-Tata, 2012).

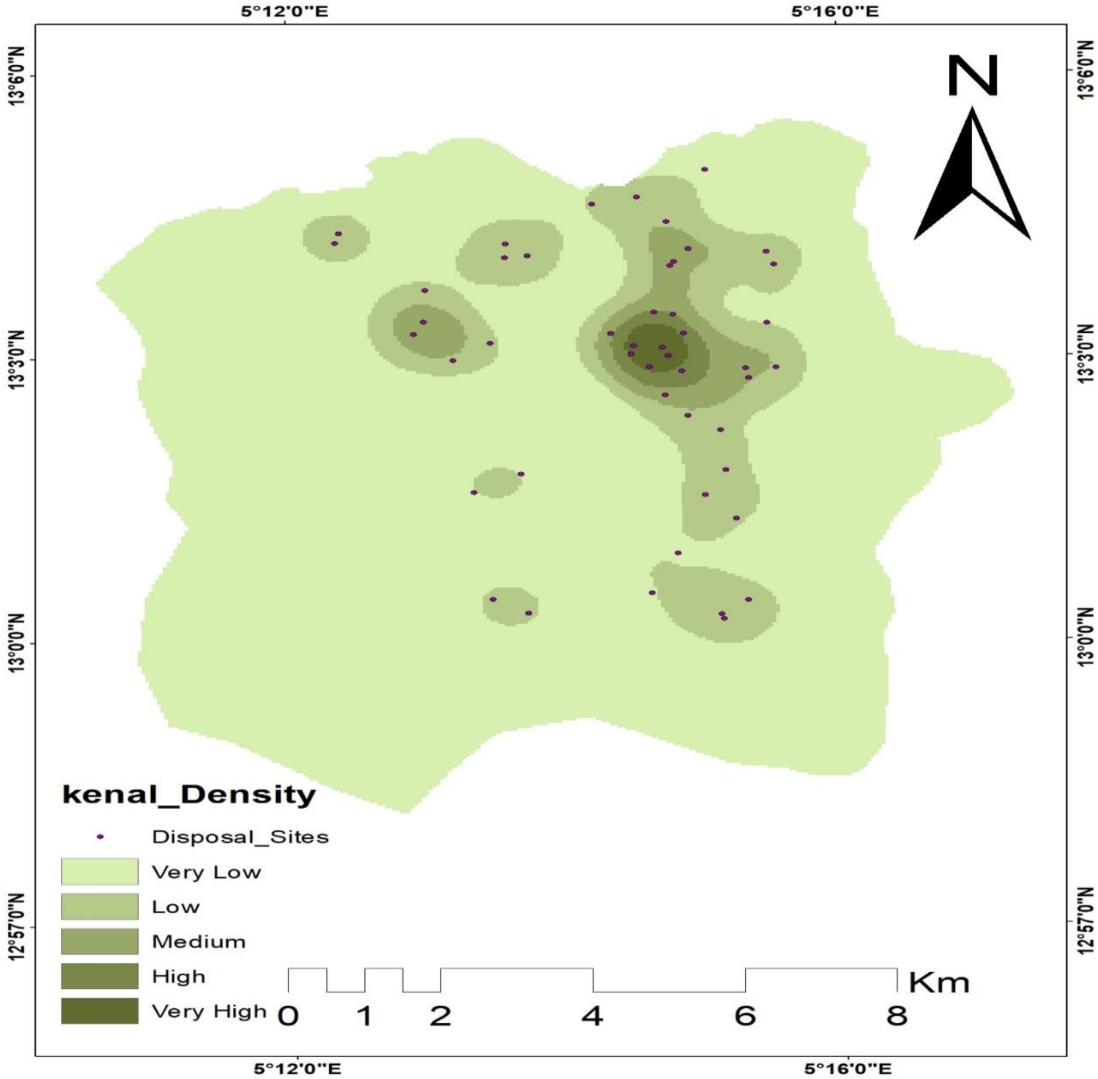

Figure 4: Kernel Density Map of Waste Disposal Sites

The spatial distribution of $PM_{2.5}$ concentration levels in the vicinity of the identified dumpsites are shown in Figure 5. The interpolated map shows some spatial variation in the distribution of $PM_{2.5}$ levels, ranging from the good category (0-15 µg/m³) to Unhealthy (56-150 µg/m³). None of the points had $PM_{2.5}$ concentrations above the hazardous level (>150 µg/m³). From the spatial distribution, it is clear that the major part of the study area falls under moderate concentration levels of $PM_{2.5}$, whereas higher concentrations are limited to few localities. It can be attributed to increased activity related to the dumping site, such as burning, decomposition of organic waste, and vehicular movement resulting from transportation of waste. There are similar cases where fine particulate matter is clustered due to waste management activities, with emissions being highly site-specific and not regionally distributed (Giusti, 2009). The formation of concentrations in the "Unhealthy for Sensitive Groups" and "Unhealthy" zones has considerable significance with regards to environmental health. The fine particulate matter ($PM_{2.5}$) can penetrate deep into the alveolar part of the lungs and also be introduced to the bloodstream, leading to respiratory and cardiovascular disorders (WHO, 2021). While the levels did not reach the hazardous threshold in any of the measurements, it was noted that some elevated concentrations had been recorded on different occasions. The bar chart presented in Figure 4.9 above indicates the categorization of the 49 waste disposal areas depending on their $PM_{2.5}$ levels. From the findings, it is clear that 11 (22.4%), 21 (42.9%), 12 (24.5%), and 5 (10.2%) sites fall into the Good (0-15 µg/m³), Moderate (1635 µg/m³), Unhealthy for Sensitive Groups (36-55 µg/m³), and Unhealthy (56 No site recorded hazardous concentrations.

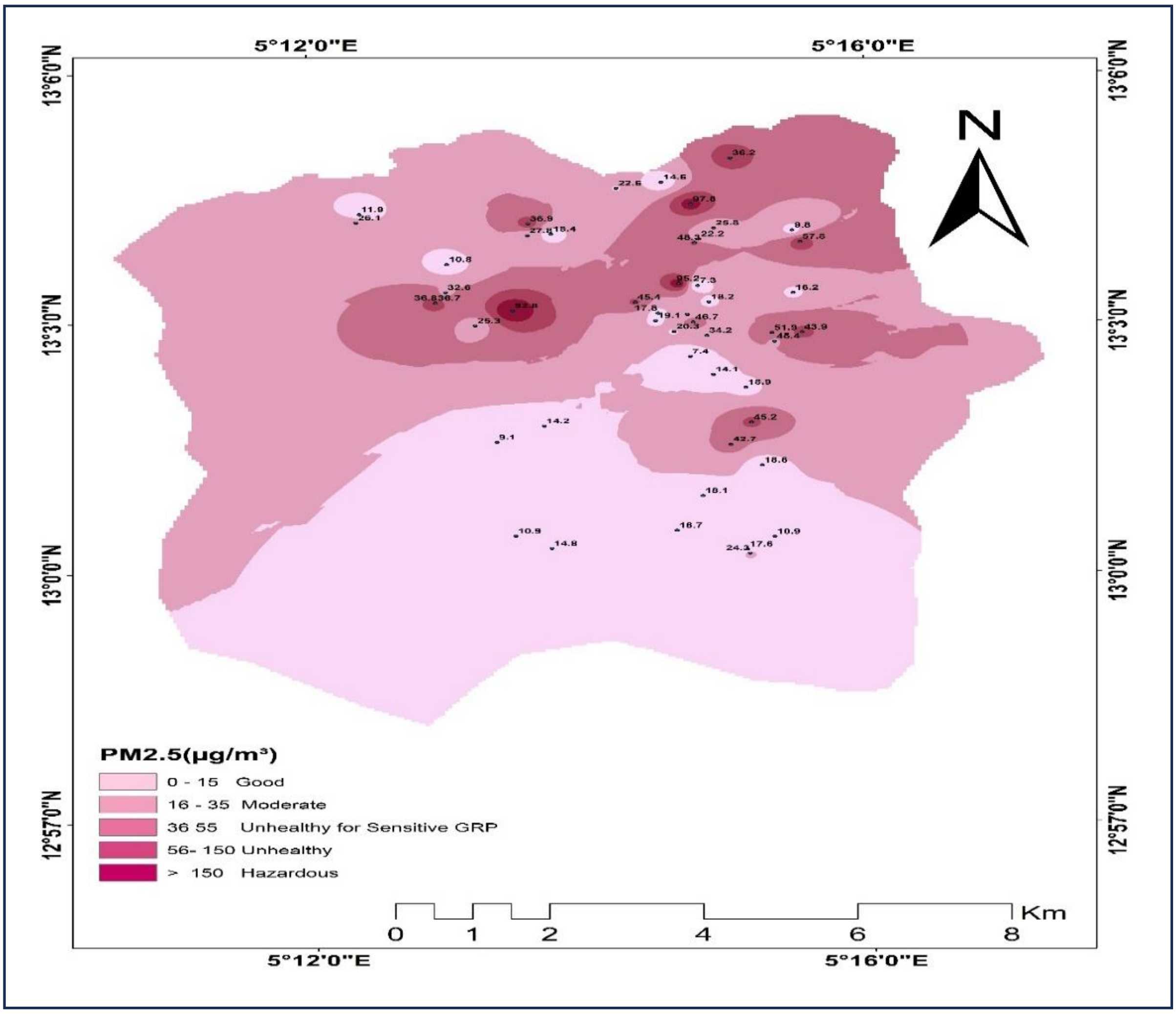

Figure 5: Spatial Distribution of $PM_{2.5}$ Concentrations

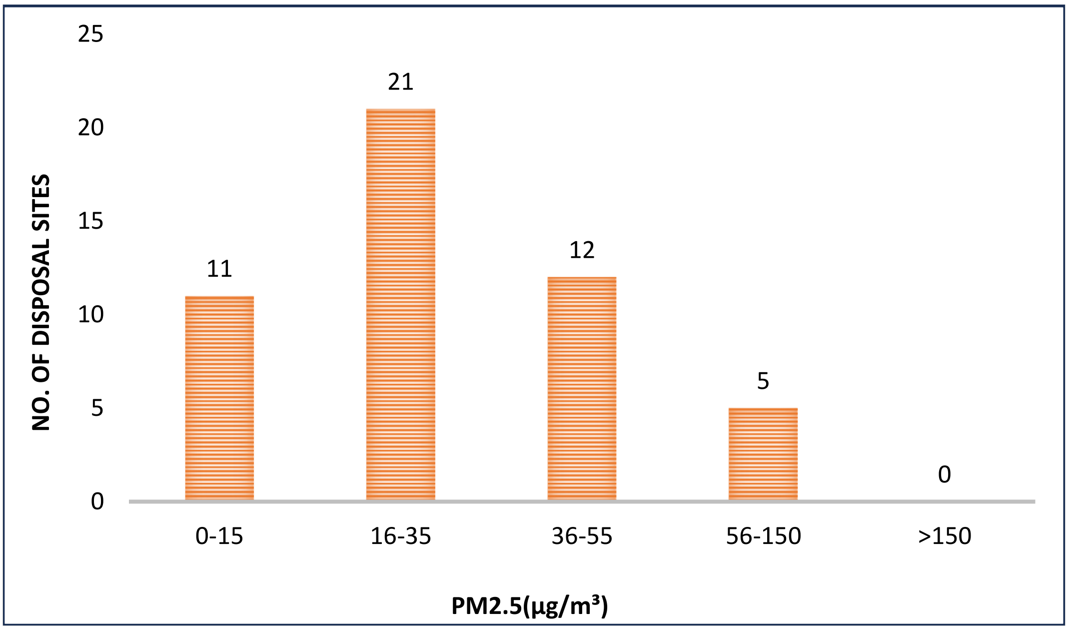

Figure 6: Distribution of Disposal Sites by $PM_{2.5}$ Concentration Categories

Figure 7. presents the spatial distribution of PM_{10} concentrations across the study area. Unlike $PM_{2.5}$, PM_{10} demonstrates a more extensive geographic range since both moderate and Unhealthy for Sensitive Groups air quality levels extend across wider regions. This trend is consistent with the nature of coarse particulates. In particular, PM_{10} comprises mechanically produced particulates from waste handling, vehicles moving on dirt access roads, wind-blown waste surface, and other dust suspension processes. Prior research has revealed the impact of coarse particulates on surface conditions and weather, which leads to greater distribution range (Kampa & Castanas, 2008). Even though most PM_{10} particles settle in the upper part of the respiratory system, their long-term inhalation can cause irritation, worsening of asthma, and lung functioning impairment (WHO, 2021). Therefore, the current distribution range implies that dust mitigation efforts at dumping sites might be ineffective, especially in dry seasons. Considering there were no high levels of PM_{10}, one could assume that industrial activities were not major sources. However, the presence of moderate PM_{10} levels indicates consistent pressure from the environment due to certain waste handling practices. The categorical distribution of the 49 waste disposal sites with regards to PM_{10} concentrations is depicted in Figure 8. From the findings, it is observed that 26 (53.1%) waste disposal sites were classified as Good (0-45 µg/m³), 18 (36.7%) as Moderate (46-100 µg/m³), and 5 (10.2%) as Unhealthy for Sensitive Groups (101-150 µg/m³). None of the sites exhibited Unhealthy or Hazardous levels.

PM_{10} particles are primarily produced through mechanical action such as handling activities, vehicle movements along unpaved access paths, wind erosion from exposed waste surfaces, and dust resuspension especially during dry weather conditions. Research indicates that coarse particles usually disperse across greater distances relative to fine particles due to surface-level disturbances and atmospheric conditions (Kampa & Castanas, 2008).

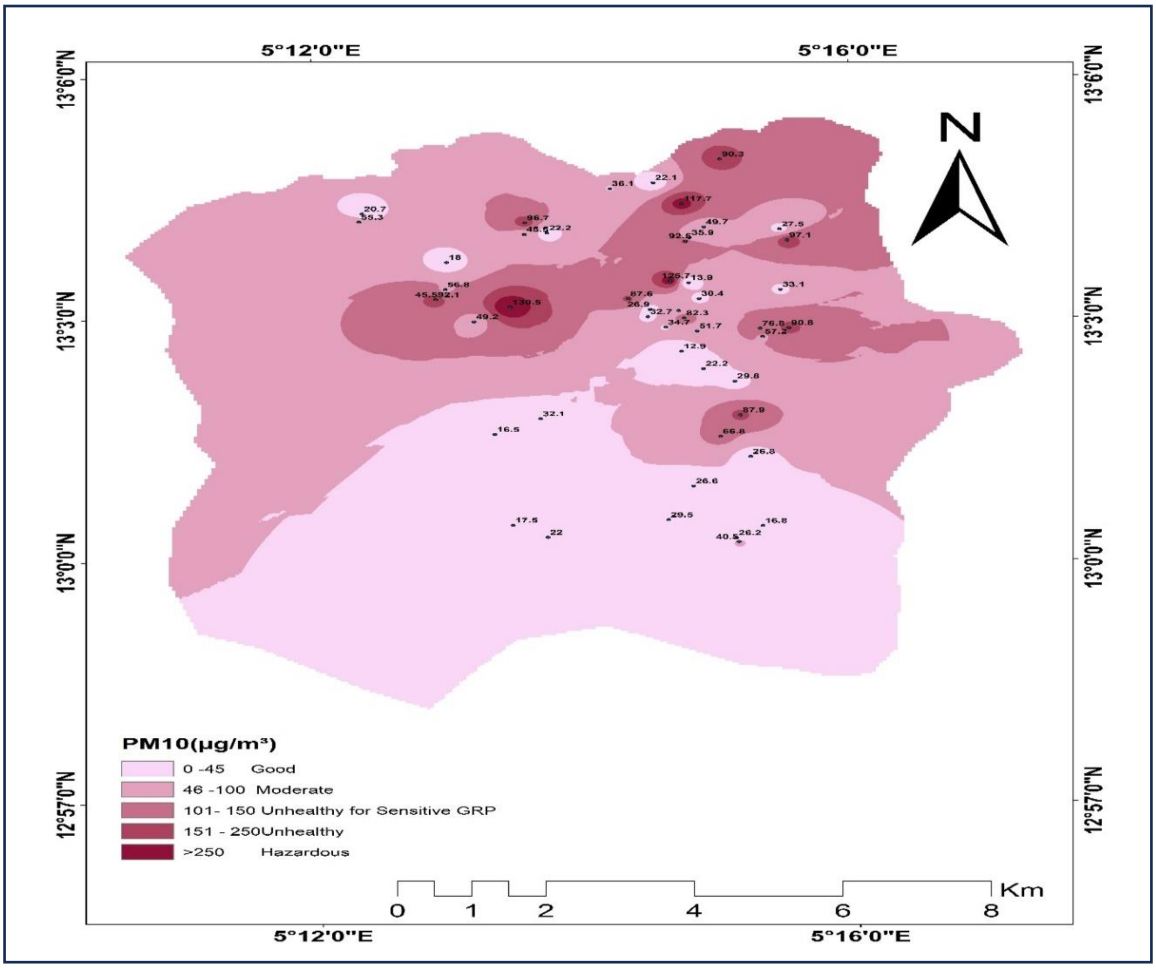

Figure 7: Spatial Distribution of PM_{10} Concentrations

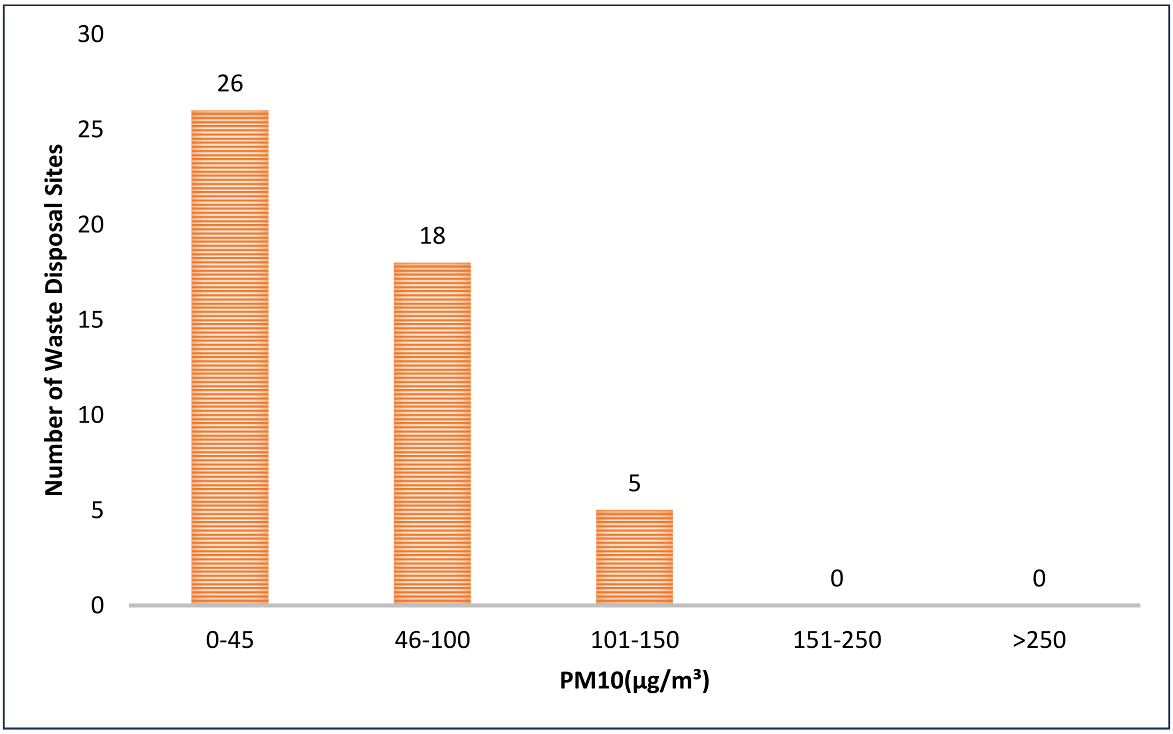

Figure 8: Distribution of Disposal Sites by PM_{10} Concentration Categories

Figure 9 shows the spatial distribution of levels of hazardous air pollutants falling within the Low, Moderate, and High classes of air pollutants. The figure indicates that most hazardous zones in the city fall under the category of moderately hazardous air pollutants, signifying the fact that hazard level from pollutants is a general phenomenon in the city rather than an isolated occurrence. Spatial clustering of zones under high hazard signifies uneven spatial distribution of pollutants, probably because of the effects of environmental factors and emissions from emission points. Spatial clustering of high risk of urban air pollutants has previously been identified through studies of environmental exposures (Jerrett *et al.,* 2015). The fact that zones are generally moderately hazardous indicates continuous exposure but not extremely hazardous exposure which has also been linked to respiratory and cardiovascular health problems (Pope & Dockery, 2016).

The figure 10. summarizes the exposure of residents to air pollutants hazard within different hazard categories as depicted in figure 9. From this figure, it is clear that most of the people reside within the moderate hazard category, and a small but environmentally significant portion of the population lives within high hazard zones. On the other hand, a relatively small number of people reside within low hazard zones. The dominance of population in moderate hazard zones demonstrates that the air pollutant hazard is a health issue and not an environment problem because of its nature. Despite being small in geographical size, High Hazard zones have higher vulnerability of residents especially children and the elderly. It should be noted that, according to WHO (2021), any level of pollution has some risks involved, even at moderate levels.

Overall, figure 10, brings out the human aspect of environment risk through the indication that a considerable population within the metropolitan area is exposed to different levels of hazards.

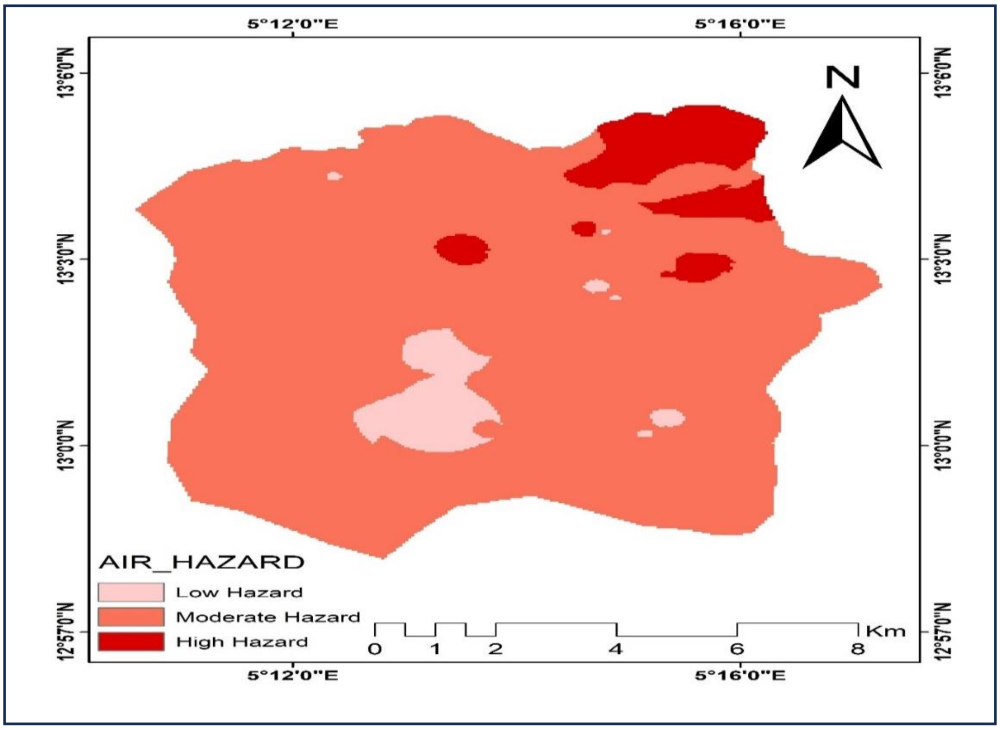

Figure 9: Spatial Distribution of Air Pollutant Hazard Levels

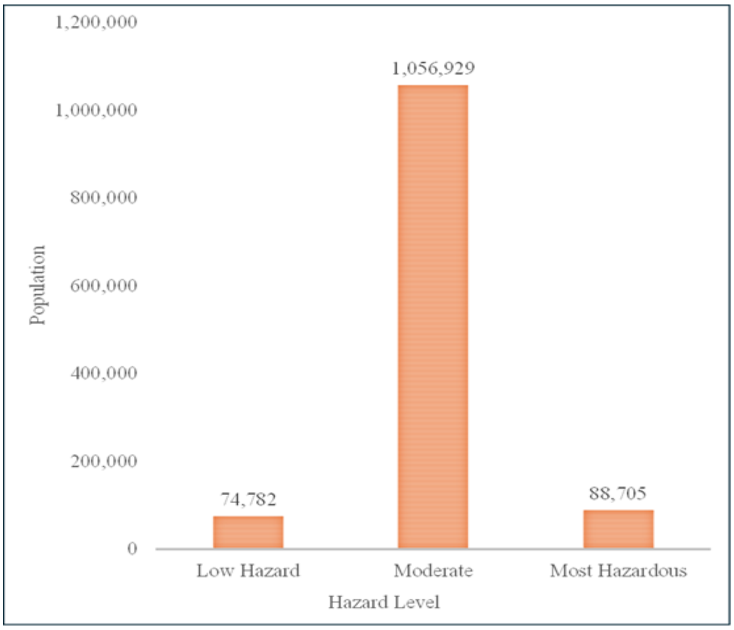

Figure 10: Population Distribution across Air Pollutant Hazard Categories

5.0 Conclusion

This study assessed the impact of waste disposal sites on air quality in Sokoto Metropolis, Nigeria, using a geospatial approach. Forty-nine active waste disposal sites were mapped via GPS field surveys. Portable monitors measured key pollutants ($PM_{2.5}$, PM_{10}), while secondary data on boundaries, roads, water bodies, and population (from WorldPop) were integrated in ArcGIS 10.8. Spatial techniques included Average Nearest Neighbor analysis to assess site distribution, Inverse Distance Weighting (IDW) for interpolating pollutant surfaces, Kernel Density Estimation for hotspots, and Multi-Criteria Decision Analysis (MCDA) for hazard zonation combined with population overlay.

The results revealed a significantly clustered distribution of waste disposal sites (Nearest Neighbor Ratio = 0.818, z = –2.438, p = 0.015), with hotspots concentrated in the central and north-eastern parts of the metropolis near residential areas. Air quality mapping showed predominantly moderate $PM_{2.5}$ and PM_{10} levels across the study area, with elevated concentrations localised around disposal sites driven by open burning, organic decomposition, and related vehicular and dust resuspension activities. Hazard zonation indicated widespread moderate-risk zones, with small high-risk clusters near active sites. Population overlay confirmed that a large proportion of residents live in moderate- to high-exposure areas, highlighting increased public health risks for vulnerable groups.

These findings underscore the urgent need for improved waste management infrastructure, strict enforcement of buffer zones, and GIS-supported urban planning to mitigate localised air pollution and protect community health in rapidly urbanising northern Nigerian cities. Adopting sustainable practices such as controlled disposal, recycling, and community awareness can reduce environmental risks and contribute to broader sustainable development goals.

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