

# Dumpsite-Induced Soil Fertility Degradation and Its Implications for Peri-Urban Agricultural Sustainability in the Niger Delta Region, Nigeria

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Date of Submission: 27-03-2026

Date of Acceptance: 06-04-2026

## Abstract

Unregulated open dumpsites in Sub-Saharan Africa, especially in rapidly urbanizing regions, pose a threat to the fertility and food production systems in the peri-urban environment. Existing literature has focused on the impacts of heavy metal contamination in the peri-urban environment, but the degradation of the fertility status of the soils, such as organic carbon, organic matter, total nitrogen, cation exchange capacity, and base cations, has not been addressed, especially in the Benin Formation in the Niger Delta region in Nigeria. This study aims to investigate the impact of dumpsite-induced degradation in the Upper Ekehuan, Asoro, open dumpsite in Ovia North-East LGA, Edo State, Nigeria, using the Soil Quality Index (SQI) based on the theory of Sustainable Land Management (SLM). Twelve soil samples were collected from the dumpsite and a control site at three depths and analyzed for the physicochemical fertility status. Results showed organic enrichment in the dumpsite but a decrease in the depths, accompanied by a decrease in pH values, which ranged from 4.98 to 5.43, and low cation exchange capacity, which ranged from 2.574 to 4.554 Meq/100g, and nutrient imbalances not conducive to agricultural soils. Using the SQI, the study found all the soils in the dumpsite to be 'poor' and 'fair,' a situation that is a departure from the common belief in the enrichment of dumpsite soils in the peri-urban environment. Recommendations were made to NESREA on the buffer zone legislation, the need to address the issue of soil remediation, and the need to address the issue of food safety in the peri-urban environment.

**Keywords:** soil quality index, organic carbon depletion, cation exchange capacity, sustainable land management, peri-urban agriculture, Niger Delta soils, open dumpsite, Nigeria

## I. Introduction

The confluence of rapid urbanization with the lack of effective management of solid waste has proved to be one of the most important failures of environmental governance in Sub-Saharan Africa (Ngoc & Schnitzer, 2022; Wilson et al., 2021). The case of Nigeria illustrates a paradigmatic example of the former, with a rapidly increasing rate of urbanization far outstripping investment in effective waste management, with the result being a proliferation of open dumpsites along the peripheries of major cities, which often overlap with agricultural land (Ogundele et al., 2021; Adewole, 2023). The bulk of the research in the domain of environmental studies has focused primarily upon the issue of heavy metal contamination, with a particular emphasis upon its toxicological consequences for groundwater as well as human health (Adesuyi et al., 2020; Nwachukwu et al., 2021). However, a substantial gap in the research has been the corresponding impact of soil fertility architecture, with a particular emphasis upon organic carbon depletion, cation exchange capacity, pH-driven nutrient immobilization, textural alteration, and corresponding agricultural sustainability (Eze et al., 2022; Mukherjee et al., 2021). While an estimated 40% of Nigerian urban populations rely, to some degree, upon peri-urban smallholder agricultural production (FAO, 2022), soil fertility degradation along the peripheries of open dumpsites poses a threat to agricultural sustainability.

The Benin Formation is the bedrock geology of Benin City and its surrounding areas. It is largely composed of highly porous sands with low clay content and low buffering capacity (Akujieze, 2004). These soils have been shown to be extremely sensitive to fertility decline from anthropogenic disturbances and tend to take long periods of time to recover from such disturbances using in situ processes (Imasuen & Omorogieva, 2013). There is a

lack of published research on the application of a Soil Quality Index framework on soils in the vicinity of the dumpsite in Edo State. The Soil Quality Index is a conceptual framework in the SLM theoretical framework used in this research. It is a multi-parameter approach used in the conversion of raw chemical data on soils into a composite index of the capacity of the soils to deliver ecosystem services (Andrews et al., 2004; Masto et al., 2022). This research is designed to answer the research question: How does the proximity of soils to the Upper Ekehuan Dumpsite affect the fertility of the soils, the cation exchange capacity of the soils, and the distribution of organic carbon in the soils? What is the implication of the findings of this research on the viability of agriculture in the peri-urban areas of Upper Ekehuan? The specific objectives of the research are as follows: To investigate the spatial and depth-dependent distribution of OC, OM, TN, CEC, and base cations in the soils; To compute the composite SQI; To classify the soils using the FAO criteria on soils in the tropics; To make policy recommendations on the findings of the research.

## II. Theoretical Framework

Soil quality – "the capacity of a specific kind of soil to function within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation" (Karlen et al., 2003, p. 1882) – is facilitated through the SQI framework (Andrews et al., 2004; Masto et al., 2022; Rahmanipour et al., 2020) in three steps: the determination of a Minimum Data Set (MDS) of soil indicators, the scoring of the indicators using non-linear membership functions, and the combination of the scores in a weighted composite index (Moebius-Clune et al., 2022; Vasu et al., 2021). This framework is embedded in Sustainable Land Management theory, which treats land degradation as a systemic failure at the nexus of waste management, land use planning, and agricultural policy (Nkonya et al., 2021). The SLM principles in the Nigerian context are contained in the National Action Programme to Combat Land Degradation and the UNCCD LDN targets.

## III. Study Area and Geological Context

The Upper Ekehuan (Asoro) dumpsite is in Ovia North-East LGA in Edo State in the Niger Delta Basin of Nigeria at coordinates 6°19'20"N – 6°19'40"N and 5°35'0"E – 5°35'20"E. The area is a basin depression with sloppy terrain conducive for the accumulation of leachate and its migration down the slope towards the soils and groundwater

systems. The land use in the surrounding area is residential and agricultural. The geology of the area is the Benin Formation – reddish-brown clayey sands laterized and overlying a layer of highly porous and crumbly white sands with interbedded clay stringers (Short & Stauble, 1967; Akujieze, 2004). The area has a tropical wet/dry climate with a mean annual rainfall of about 1,800–2,200 mm (Ileojie, 1981).

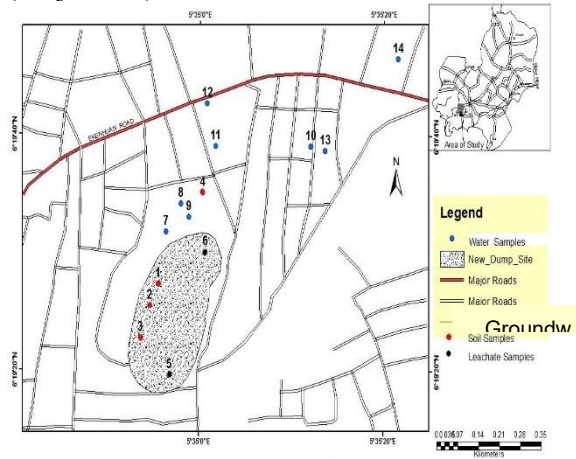


FIG. 1: MAP OF AREA OF STUDY SHOWING THE SAMPLED LOCATIONS

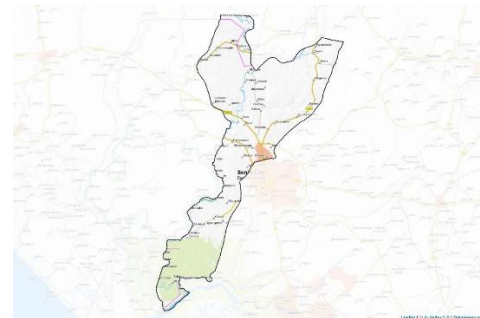


Figure 2 Map of Ovia North East

## IV. Materials and Methods

### 4.1 Sample Collection and Preparation

Twelve soil samples were collected at four locations, three locations at the active dumpsite zone, and one location at the control site, 600 meters away from the dumpsite perimeter. At each location, three increments at 0-10, 10-20, and 20-30 cm depths were sampled using a soil auger. GPS readings were taken at each location.

### 4.2 Laboratory Analytical Methods

pH was measured in a 1:2.5 H<sub>2</sub>O/soil mixture using a pH meter (Davey & Conyers, 1988). Organic carbon content was determined using the Walkley-Black wet oxidation procedure (Nelson & Sommers, 1982). Organic matter content was computed using the Van Bemmelen factor, 1.724. Total nitrogen

content was determined using the Kjeldahl digestion procedure (Bremner, 1965). CEC was determined using the ammonium acetate procedure at pH 7.0 (McLean, 1982). Exchangeable bases, such as Na<sup>+</sup>, K<sup>+</sup>, Mg<sup>2+</sup>, and Ca<sup>2+</sup>, were determined using flame photometry. Available phosphorus, such as PO<sub>4</sub><sup>3-</sup>, was determined using the Bray-Kurtz No. 1 procedure (Bray & Kurtz, 1945). Particle size analysis was done using the hydrometer method (Bouyoucos, 1962).

#### 4.3 Soil Quality Index Computation

The SQI was computed using the equation  $SQI = \sum(W_i * S_i)$ , where  $W_i$  is the weight and  $S_i$  is the score computed using a non-linear membership function. The MDS consisted of the following seven attributes: pH, OC (%), TN (%), CEC, available P, K<sup>+</sup>, and Clay (%).

SQI classification is as follows: Poor (< 0.35), Fair (0.35-0.55), Good (0.55-0.75), and Excellent (> 0.75) (Rahmanipour et al., 2020).

### V. Results

#### 5.1 Soil pH and Electrical Conductivity

Soil pH varied from 4.98 to 5.43, consistently in the acidic range in all sampling points and depth intervals. The values are consistently low, well outside the FAO optimal range of 6.0-7.0 for tropical agricultural production, and therefore indicate that nutrient immobilization due to pH is a major constraint to crop productivity in tropical regions. Electrical conductivity varied from 52-92  $\mu\text{S}/\text{cm}$ , highest at shallow depth and at dumpsite-proximate sampling points.

#### 5.2 Organic Carbon, Organic Matter, and Total Nitrogen

At 0-10 cm depth, SL2 has the highest OC at 4.76%, followed by SL1 at 3.54% and SL3 at 3.11%, which are higher than SL4, the control, at 2.54%. At 20-30 cm depth, however, OC values drop significantly at SL1 (2.16%), SL2 (2.06%), and SL3 (1.43%). More alarming, however, is the OC of 1.89% at 10-20 cm depth in SL2, which is actually lower than SL4 at 2.21%. This indicates subsurface soil organic matter depletion, which is in line with the priming effect theory of Kuzyakov (2021), which explains that the addition of labile organic matter leads to the acceleration of microbial mineralization of stable native soil organic matter, resulting in a net loss of soil carbon. Total nitrogen peaks at 0.57% at 0-10 cm depth in SL2, then drops significantly at 20-30 cm depth, and even more at 10-20 cm depth, which is at 0.09%. The low pH environment suppresses nitrification, which is a major constraint

#### 5.3 Cation Exchange Capacity and Base Cations

CEC values range from 2.574 to 4.554 Meq/100g, and all values fall under the 'very low' category, as per the FAO minimum threshold of 10-15 Meq/100g for tropical soils. At 20-30 cm, CEC values for SL1 soil decrease to 2.574 Meq/100g, which is the minimum value for this dataset. It is indicative of severe subsoil exchange capacity loss due to leaching by acidic percolating solutions. Calcium values, ranging from 0.78 to 1.38 mg/kg, are significantly lower than the 40 mg/kg minimum for agricultural soil to be considered productive (Sparks, 2003). Sodium, which is enriched in the surface soil of the dumpsite, competitively displaces Ca<sup>2+</sup> and Mg<sup>2+</sup> from exchange sites and has a detrimental effect on soil structure over time.

#### 5.4 Textural Analysis

Sand contents vary between 48.68% and 53.65%, silt contents vary between 12.90% and 23.80%, and clay contents vary between 25.52% and 33.45%. Clay contents increase in subsurface depths, indicating illuviation resulting from leachate percolation. The sandy nature of the soil indicates high erosion susceptibility, low structure stability, and a high likelihood of being exacerbated by the destruction of the vegetation around the dumpsite.

#### 5.5 Soil Quality Index Results

All samples collected from the dumpsite locations, regardless of their depths, fall under the 'Poor' category (< 0.35) to 'Fair' category (0.35-0.55). The highest SQI values (0.41-0.43) are obtained from 0-10 cm depths in locations SL2 and SL3. All samples collected from 20-30 cm depths fall under the 'Poor' category (SQI: 0.22-0.31). SL4, which is the control site, records slightly higher SQI values (0.34-0.38). This indicates that undisturbed Benin Formation soils tend to maintain a stable fertility profile, albeit with low fertility values.

### VI. Discussion

#### 6.1 Reinterpreting Organic Enrichment Near Dumpsites

Enrichment of organic matter around the dumpsite is superficial in both spatial extent (limited to 0-10 cm depths) and functionality (limited to pH 4.98-5.43, which is very inhibitory to nitrogen conversion to a usable form by plants, in addition to aluminum and manganese toxicity to plant roots). This phenomenon is in line with what was proposed by Adewuyi&Opasola (2021) under the 'organic matter decoupling' concept, whereby organic matter is rendered nonfunctional in soil fertility cycles by the prevailing acidic conditions. Contrarily, the subsurface OC depletion in dumpsite locations

compared to their depths in undisturbed locations is in line with the 'priming effect theory' proposed by Kuzyakov (2021).

### 6.2 CEC Deficiency as the Critical Agricultural Constraint

None of the samples recorded CEC above 4.554 Meq/100g. In a high rainfall setting such as in Edo State, which records 1,800-2,200 mm rainfall annually, CEC is a major constraint in soil fertility since rainfall will leach out soil nutrients beyond the root zone after every rainfall event (Sparks, 2003; Mukherjee et al., 2021). For smallholder farmers, soil types in dumpsite areas are not only less fertile than the regional baseline but will also lose any applied fertilizers, thus raising costs of agricultural production in the area.

### 6.3 Depth Stratification and Root Zone Implications

The high concentration of organic matter, nitrogen, and base cations in the 0-10 cm soil layer indicates a shallow soil layer or a 'shallow fertile veneer' that is highly susceptible to erosion. Where this layer is disturbed by farming activities, the layers beneath, which are characterized by low OC (1.43-2.16%), low CEC, and acidic pH, are exposed to the surface, thus becoming the root zone. This is particularly a problem in root crop farming, which requires a high level of soil structure in the subsoil to a depth of 25-40 cm.

### 6.4 Phosphate and Potassium Dynamics

Phosphate concentration is extremely low, ranging between 1.04-1.84 mg/kg, which is way below the 10-15 mg/kg required in tropical regions. Phosphate is an extremely deficient nutrient in this soil, which is a major problem in agricultural production. Phosphate is immobilized in iron and aluminum oxides in acidic environments (Bolan et al., 2021). High Na/K ratios are recorded in several samples in the dumpsite surface soil, which could cause potassium to competitively inhibit  $K^+$  uptake, leading to a potassium deficiency in plants, even in the presence of  $K^+$ .

### 6.5 Implications for Peri-Urban Food Systems

The 'Poor' to marginal 'Fair' SQI classification is relevant to SDG 2: Zero Hunger, and SDG 15: Life on Land. The world over, an estimated 2.4 billion people rely on peri-urban agriculture for a significant portion of their dietary needs (FAO, 2022); in Nigeria, it is worsened by the volatilities in foodstuff pricing and cold storage facilities. The deterioration of peri-urban soils

adjacent to dumpsites translates to dietary insecurity for urban poor populations.

## VII. Policy Implications and Recommendations

A minimum buffer zone of 500 meters is recommended between unregulated open dumpsites and areas used for agriculture, as provided for in the Physical Planning and Development Act of Nigeria. The liming of peri-urban soils adjacent to open dumpsites is recommended for Edo State Agricultural Development Programme. This will increase soil pH from 5.0-5.4 to 6.0-6.5, greatly improving nutrient availability, promoting nitrification, and increasing effective CEC. The priming effect dynamics imply that increasing organic matter without corresponding improvement in soil pH will not improve soil fertility. Integrated Soil Fertility Management (ISFM) is recommended as a package for improving soil fertility. ISFM is a combination of lime application, mineral fertilizer micro-dosing, and cover cropping, as provided for by Vanlauwe et al. (2022). A food safety monitoring program for crops grown within a 500-meter radius of open dumpsites is recommended for NAFDAC. This program should be a mandatory requirement for all gazetted dumpsites in Edo State.

## VIII. Conclusion

This research has shown that the Upper Ekehuan dumpsite causes soil fertility degradation, which is agriculturally significant, in the soil samples from all depth intervals. The SQI method indicates that the overall soil quality of the samples lies in the 'Poor' to marginal 'Fair' range, with progressive deterioration with depth. The inherently low buffering capacity of the Benin Formation soil accentuates the fertility degradation. The research shifts the focus from the specific issue of toxic contamination of soil from the dumpsite to the broader issue of land capability, which indicates that the proximity of the soil to the dumpsite has a negative impact on agricultural productivity through several fertility-related mechanisms. The research should be taken further to cover a broader range of SQI method application along the spatial gradient, with biological parameters to cover the entire range of SQI, which includes physical, chemical, and biological parameters.

### Author Contributions

M.E.O.: Conceptualization, data collection, laboratory analysis, writing—original draft.  
A.D.O. , methodology review, writing—review and editing.

### Acknowledgement

The author of this research wishes to acknowledge the moral support of my supervisor, Prof E.G Imeokparia, for his criticism and guidance.

**Funding:** This research did not receive any external funding.

### Competing Interests

The authors of this manuscript have no competing interests in relation to this manuscript.

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