



Influence of Rice Mill Solid Waste on Soil Quality in Gboko Rice Mill of Benue State, Nigeria

¹Gesa, T.R., ²Apuu, J. ³Surma, S.K.

^{1,2&3} Department of Agricultural Technology, Federal Polytechnic Wannune, Benue State, Nigeria

*Corresponding author: drgesarichard4@gmail.com

Abstract

Laboratory and field experiments were carried out during the dry season of 2023 to determine the influence of rice mill solid waste dumpsites on soil quality in Gboko rice mill in Benue State. Soil samples were collected at the depth of 0–30 cm at five (5) distances (1 m, 50 m, 100 m, 150 m and 200 m) away from the dumpsite. The soil sample taken at the 200 m in the location not subjected to waste disposal served as control. These samples were air-dried and analysed for particle size distribution, pH, organic carbon, total nitrogen, sulphur, available phosphorus, exchangeable bases, nitrates, sulphates, phosphates, base saturation, exchangeable sodium percentage, electrical conductivity and selected heavy metals (Cd, Pb, Cr, Zn and Mn). The results indicated that the parameters examined in the soil samples in the location showed a decrease in concentration with distance away from the dumpsites, except Fe and Al. Heavy metal concentration in soil at the location was below permissible safe limits, except in soils for Cd which was slightly above these limits. It was concluded that rice mill solid waste significantly influenced various measurable soil properties. Continuous monitoring of these quality indices would be required to avoid contamination of soils within the vicinity of the dumpsites. Remediation for Cd in soils of the location would also be necessary.

Keywords: Dumpsite, contamination, concentration, quality, remediation.

1. Introduction

The soil acts as a physical, chemical and biological filter as well as the receptacle for all materials buried and disposed of beneath and on the surface. Soil quality is the capacity of a specific kind of soil to function within natural and managed ecosystem boundaries to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation (USDA, 2001). More recently, soil quality has come to refer to the dynamic quality of soils, defined as the changing nature of soil properties resulting from human use and management (Larson & Pierce, 1994). Collectively, these properties determine the inherent quality of a soil. They help compare one soil with another and evaluate soils for specific use (Seybold et al., 2014; Larson & Pierce, 1994; Brady & Weil, 1999). Soil pollution usually originates from development of industries, intensive agriculture associated with modern systems of cultivation, use of sewage, sludge, city composts and other industrial wastes. The contaminants produced by industrial processes reach the soil through the air (gaseous and particulate contaminants), through drainage systems (industrial effluents and water drainage) and through direct mechanical or gravitational effects on the soil solid materials that can be dumped directly onto agricultural land (Wuana & Okieimen, 2011).

Commercial rice milling activities commenced in the early eighties in Benue State and the volume of activity in this industry has progressively increased over time. As a consequence, large volumes of rice mill solid waste are disposed on the surface of the soil in most areas where rice milling is carried out. The practice at the Gboko rice mill is not different. The rice husk waste that is generated can be harmful to the environment. These wastes often contain a considerable amount of toxic compounds and metals, which always contaminate the soil and water. The rice husk dust poses a serious risk to groundwater contamination due to surface runoff and can lead to ground and surface water contamination (Olatunji & Ayuba, 2011). The high nutrient content in rice husk suspended and dissolved in water can deplete dissolved oxygen in the water which can lead to the death of aquatic organisms (United States Environmental Protection Agency, 1999).

These wastes which are dumped on the surface of the soil, apart from being an eyesore, pollute the soil, ultimately affecting human health. The decomposing solid wastes in soils also produce toxic vapours (Uguru et al., 2015). The husk is disposed on open land very close to the milling centre. These overgrown heaps of rice waste cause environmental nuisance and contribute to the loss of nutrients to runoff water, thus reducing the soil quality since these soil nutrients are not recycled. Most millers do not know how to dispose of these wastes apart from using these wastes to litter the nearby environment (Mbah, 2006). In spite of the magnitude of these wastes which are generated on a daily basis and their possible adverse effects on the environment such as pollution, till today no serious attempt has been made either for their effective utilization or safe disposal (Nnabude & Mbagwu, 2001). This study was therefore carried out to:

- i. Determine the effect of rice mill solid wastes on soil quality.
- ii. Evaluate the heavy metal status of soils around the areas under investigation.

2. Literature Review

2.1 Soil Quality and its Assessment

Soil quality is a multifaceted concept that integrates physical, chemical, and biological properties to reflect the capacity of soil to function within ecosystem boundaries. According to USDA (2001), soil quality is 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. (1997) described soil quality as "the fitness for use" of a soil, emphasizing its dynamic nature and responsiveness to management. Larson and Pierce (1994) defined soil quality as the capacity of soil to function within ecosystem and land-use boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health. Seybold et al. (2014) quantified soil quality through a range of measurable indicators including soil texture, organic matter content, pH, cation exchange capacity (CEC), base saturation, and nutrient availability. These indicators serve as proxies for the physical, chemical, and biological processes that determine soil function. According to Brady and Weil (2015), the textural class of a soil is a basic property that is not readily subject to change, while chemical properties such as pH and organic carbon content are dynamic and responsive to management practices.

2.2 Rice Mill Waste and Its Environmental Impact

Rice milling generates substantial quantities of solid waste, primarily rice husk, which constitutes approximately 20% of the paddy rice weight (Olatunji & Ayuba, 2011). The disposal of this waste poses significant environmental challenges, particularly when dumped indiscriminately on land. Rice husk is characterized by high silica content (15–22% by weight), which makes it resistant to natural decomposition (FAO, 1994). The organic components of rice husk decompose slowly, releasing nutrients into the soil over time, while the inorganic silica fraction remains persistent. Nnabude and Mbagwu (2001) investigated the physicochemical properties and productivity of a Nigerian Typic Haplustult amended with fresh and burnt rice mill wastes. Their study found that rice mill waste application improved soil physical properties, including increased aggregate stability and improved water-holding capacity. However, the study also noted the potential for nutrient immobilization during the initial stages of decomposition. Mbah (2006) reported that organic wastes, including rice mill waste, influenced plant growth parameters and nutrient uptake by maize, with responses varying depending on the waste type and application rate.

In a study conducted in Abakaliki, southeastern Nigeria, Nwite and Azuka (2019) examined the impact of rice mill wastes dump on soil physicochemical properties. Soil samples were collected at four distances from the dump and analysed for bulk density, total porosity, gravimetric moisture content, pH, phosphorus, nitrogen, organic carbon, exchangeable bases, CEC, exchangeable acidity, and base saturation. The results showed significantly ($P < 0.05$) elevated physicochemical properties at 50 m distance from the dump, with values diminishing at greater distances. The authors recommended that rice mill wastes, if properly managed, could serve as a veritable amendment material for soil fertility improvement and sustainable productivity. Ifejimalu (2018) conducted a two-year study (2015 and 2016) in Abakaliki, Ebonyi State, to determine the effects of heavy dumping of rice mill wastes on soil properties. Samples were collected from three topographic positions (crest, mid-slope, and lower slope) at the rice mill industry and from a control site. The results indicated that rice mill waste dumping significantly altered soil chemical properties, with the greatest impact observed at the lower slope position where waste accumulation was highest. Similarly, Odoh (2014) assessed soils in the vicinity of a rice mill industry in Otukpo, Benue State, for potential heavy metal contamination. The concentrations of Cd, Co, Cr, Cu, Mn, Ni, Pb, and Zn were determined by flame atomic absorption spectrometry, and the overall results indicated that heavy metal concentrations were elevated near the mill premises compared to background levels.

A GIS-based analysis by Odeh et al. (2024) examined the spatial distribution of heavy metals around Otukpo rice mill in Benue State. Soil samples were collected from ten locations and analysed for Cd, Cu, Pb, Ni, Zn, Hg, Fe, As, and Cr using atomic absorption spectrophotometry. The results revealed that iron had the highest concentration at the entrance point (3.92 mg/kg) and lowest at the generator house (1.12 mg/kg). The husk dumpsite recorded the highest concentration of copper (0.666 mg/kg), while the drying point recorded the least (0.088 mg/kg). The study highlighted the effectiveness of GIS in mapping heavy metal concentrations and recommended regular monitoring of the area. Yahaya et al. (2026) assessed soils affected by rice mill effluents in Birnin Kebbi, Nigeria. The soils were slightly acidic (pH 6.20–6.62), and electrical conductivity exceeded WHO guidelines in the North (1,510 $\mu\text{S}/\text{cm}$) and West (1,570 $\mu\text{S}/\text{cm}$) directions. Heavy metal analysis revealed elevated iron concentrations (10.90–13.60 mg/L) that exceeded NSDWQ and WHO guidelines, while zinc (6.90 mg/L) and copper (2.00 mg/L) also exceeded permissible limits. Positive correlations were observed between physicochemical parameters and heavy metals, suggesting a common source. Although current exposure posed no immediate health risk, the study emphasized the need for routine monitoring and improved pollution control measures.

2.3 Heavy Metals in Soils: Sources, Behaviour, and Effects

Heavy metals are metallic elements with an atomic weight greater than that of iron (55.5 g mol^{-1}) or density greater than 5.0 g cm^{-3} (Anjembe et al., 2018). They are present at relatively low concentrations in soils, plants, and natural waters. Rakshit et al. (2017) defined heavy metals as a consortium of transition metals, metalloids, lanthanides, and actinides having a density of 5.0 Mg m^{-3} or more and atomic weight greater than that of calcium. They occur naturally in several rock-forming minerals; however, when concentrations are raised above permissible limits due to anthropogenic or geogenic activities, heavy metal pollution occurs. Titler (1986) classified heavy metals into essential and toxic categories based on their role in biological systems. Essential heavy metals such as Zn, Cu, Mn, and Fe are required for normal plant and animal metabolism, while non-essential metals such as Cd, Pb, Cr, and Hg are toxic even at low concentrations. According to Alloway (1995), the behaviour of heavy metals in soil is governed by a complex interplay of physical, chemical, and biological processes. Adsorption to soil particles, precipitation as insoluble compounds, complexation with organic matter, and uptake by plants are the major processes determining the fate of heavy metals in soil-plant systems.

Kabata-Pendias (2011) reported that soil pH is the single most important factor controlling the mobility and bioavailability of heavy metals. At low pH, metal cations are more soluble and thus more available for plant uptake, whereas at neutral to alkaline pH, they tend to precipitate as hydroxides, carbonates, or phosphates. Soil organic matter also plays a critical role, forming stable complexes with metal cations and reducing their mobility (Brady & Weil, 2015). The cation exchange capacity of soil determines its capacity to retain exchangeable metal cations and thus influences their leaching potential (Rakshit et al., 2015). The toxicological significance of heavy metals in soils arises from their non-biodegradability, long biological half-lives, and potential for accumulation in

different body organs (Alloway, 1995). Cadmium is of particular concern because it can accumulate in the kidneys and liver, causing renal dysfunction, bone demineralization, and cardiovascular problems (Goyer & Clarkson, 2001). Lead is a neurotoxin that affects cognitive development in children and causes hypertension and kidney damage in adults (Titler, 1986). Chromium in its hexavalent form is a known carcinogen, while zinc and manganese, though essential micronutrients, can cause toxicity when present in excess (Kabata-Pendias, 2011).

2.4 Heavy Metal Contamination in Nigerian Soils

Heavy metal contamination of agricultural soils is a growing concern in Nigeria, driven by industrial activities, mining, agricultural inputs, and waste disposal. Umar et al. (2025) assessed heavy metal levels in vegetables grown on abandoned refuse dumpsite soil in Mubi Metropolis, Adamawa State. The concentrations of Cd, Pb, Ni, As, Cr, and Co were determined, and the results showed that arsenic levels in soil and vegetables exceeded FAO/WHO limits, indicating potential carcinogenic risk. The study underscored the need for regular environmental monitoring and sustainable agricultural practices.

Onakpa et al. (2018) reviewed heavy metal contamination of food crops in Nigeria and reported that Cd, Pb, and As are the most problematic contaminants, with concentrations frequently exceeding regulatory limits in areas affected by mining, industrial activities, and waste disposal. The authors emphasized the importance of source identification and remediation for protecting public health. Laoye et al. (2025) conducted a nationwide assessment of heavy metal contamination in Nigerian agricultural soils and found that the majority of soils were contaminated with one or more heavy metals, with Cd and Pb being the most widespread.

2.5 Heavy Metal Limits and Regulatory Standards

The establishment of regulatory limits for heavy metals in soils is critical for protecting human health and ecosystem integrity. Al-Jaboobi (2014) provided a comprehensive set of safety limits for heavy metal concentrations in soils, which have been adopted for the present study. These limits are based on extensive toxicological data and represent the maximum permissible concentrations below which adverse effects are unlikely to occur. Table 1 presents the safety limits for the heavy metals evaluated in this study.

Table 1: Safety Limit of Heavy Metal Concentration (mg kg⁻¹) in Soil

S/No.	Metal	Concentration
1	Fe	—
2	Cu	100
3	Zn	300
4	Mn	2000
5	Ni	50
6	Cr	100
7	Cd	3.0
8	Pb	100

Source: Al-Jaboobi (2014)

The World Health Organization (2004) has also established guidelines for heavy metals in drinking water and agricultural soils, which provide a basis for comparison. The European Union (2002) set limits for Cd (1 mg kg^{-1}), Pb (100 mg kg^{-1}), and Zn (150 mg kg^{-1}) in agricultural soils, while the United States Environmental Protection Agency (1999) established similar regulatory standards under the Clean Water Act and the Safe Drinking Water Act.

3. Materials and Methods

3.1 Study Area

The study was conducted at the Gboko rice mill in Gboko Local Government Area of Benue State, Nigeria. Gboko is located in the Guinea Savannah ecological zone, characterized by a tropical climate with distinct wet and dry seasons. The area is one of the major rice-producing regions of Benue State, with numerous rice milling operations generating substantial quantities of solid waste.

3.2 Soil Sampling

Surface soil samples (0–30 cm) were collected from the Gboko rice mill at five different distances away from the dumpsites (1 m, 50 m, 100 m, 150 m, and 200 m). These samples were taken during the dry season of 2021 around the rice mill location. The soil samples taken at 200 m away from the rice mills in the location not subjected to waste disposal served as control. The collected samples were air-dried, ground, and sieved to pass through a 2 mm sieve for laboratory analysis.

3.3 Laboratory Analysis

Subsamples of the sieved soils were analysed for the following parameters using standard laboratory protocols: Particle size analysis was determined by the hydrometer method of Bouyoucos (1951). Soil pH was determined by the glass electrode in 1:2 soil:water ratio and in a 1:1 soil:KCl ratio suspensions. Organic carbon was determined by the chromic acid oxidation procedure of Walkley and Black (1934). Total nitrogen was determined by the modified Kjeldahl digestion procedure (Bremner & Mulvaney, 1982). Available phosphorus was determined by Bray-1 extraction, and the concentration of P in the extracts was determined colorimetrically. Exchangeable bases were determined by neutral ammonium acetate saturation. Sodium and potassium in the extracts were determined by the flame photometer, while calcium and magnesium were determined by the Atomic Absorption Spectrophotometer (AAS). Effective cation exchange capacity was determined by summation and calculation (Njoku & Mbah, 2012). Base saturation was calculated as: $BS = (TEB / ECEC) \times 100$. Nitrates, sulphates, and phosphates were also analysed from the soil samples collected. Heavy metals (lead, cadmium, chromium, zinc, and manganese) were extracted by the single acid solution, double acid mixture, and the diethylenetriaminepentaacetic acid (DTPA) extraction procedure (Udo et al., 2009). The concentration of the metals in the filtrates was determined by absorption spectrophotometry.

3.4 Statistical Analysis

Data generated were subjected to analysis of variance (ANOVA) using standard statistical procedures. Means were separated using the Duncan Multiple Range Test (DMRT) at $P < 0.05$ (Duncan, 1955).

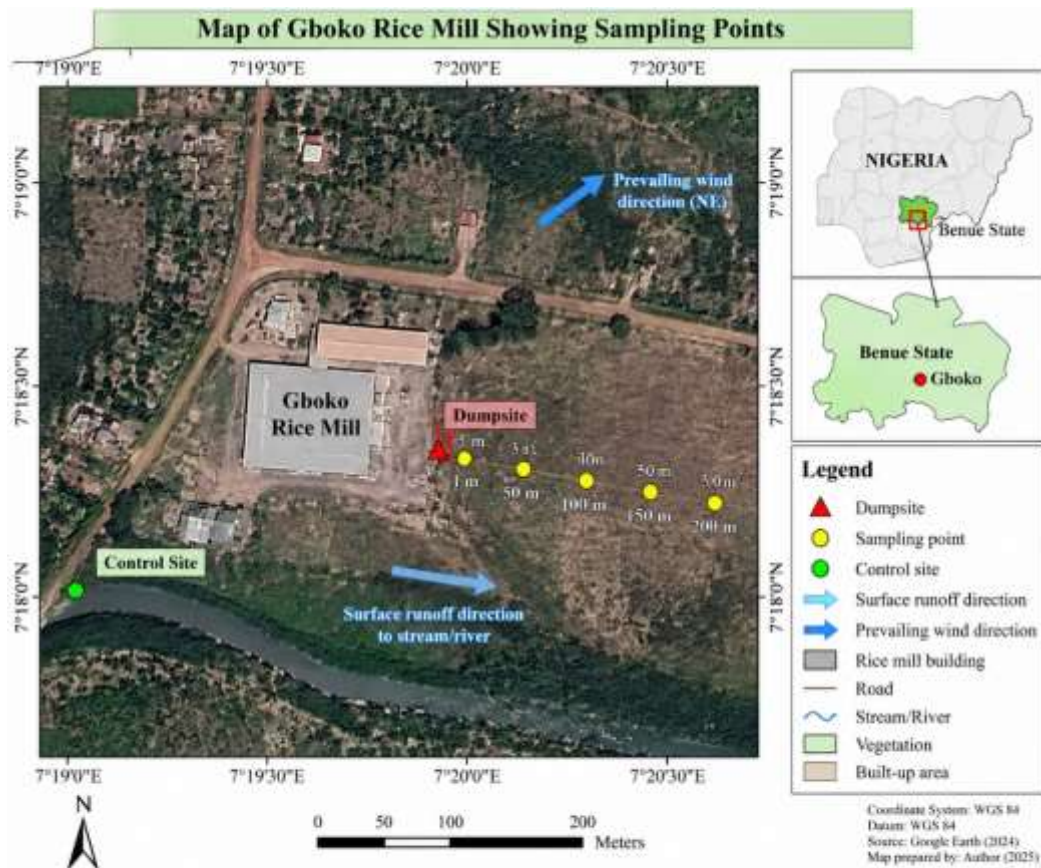


Figure 1: Map of Gboko rice mill showing the sampling points at 1 m, 50 m, 100 m, 150 m, and 200 m away from the dumpsite. The map also indicates the location of the dumpsite, the control site, and the direction of prevailing winds and surface runoff.

Figure 1: Map of Gboko Rice Mill Showing Sampling Locations and Environmental Flow Pathways

4. Results and Discussion

4.1 Mechanical Composition of the Experimental Soils

The mechanical composition of the soils under study is presented in Table 2. At the Gboko rice mill and at a depth of 0–30 cm, the composition of sand was found to be 75.0% at the dumpsite. This decreased to 72.0% at 50 and 100 m away from the dumpsite. A sand content of 71.0% was obtained at 150 m away from the dumpsite and 68.0% at 200 m (control) away from the dumpsite. Silt content was found to be 20.0% at the dumpsite, 18.0% at 50 and 100 m away from the dumpsite, and 17.0% and 15.0% respectively at 150 and 200 m (control) away from the dumpsite. Clay content was also variable and was found to be 17.0% at the dumpsite, 13.0% at 50 m, 12.0% at 100 m, and 11.0% at 150 and 200 m (control) away from the dumpsite. The texture of the soil at this rice mill was determined as sandy loam.

Table 2: Mechanical Composition of the Soil in the Location

Location	Distance from Dump Site (m)	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Textural Class (USDA)
Gboko	1	0–30	75.0	20.0	17.0	Sandy loam
	50	0–30	72.0	18.0	13.0	Sandy loam

Location	Distance from Dump Site (m)	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Textural Class (USDA)
	100	0–30	72.0	18.0	12.0	Sandy loam
	150	0–30	71.0	17.0	11.0	Sandy loam
	200	0–30	68.0	15.0	11.0	Sandy loam

The textural class of soils at all distances was determined to be sandy loam. According to Brady and Weil (2015) and Das (2015), texture is a basic property of soil that is not readily subject to change through management practices. The observed textural uniformity across the sampling distances is consistent with this principle. Foth (1990) reported that the particle size distribution determines the coarseness or fineness of soil and influences water absorption, storage, tillage ease, and aeration status. The sandy loam texture observed in this study is typical of soils in the Guinea Savannah zone of Nigeria and is generally suitable for rice cultivation, although it may have limited water-holding capacity compared to heavier textured soils.

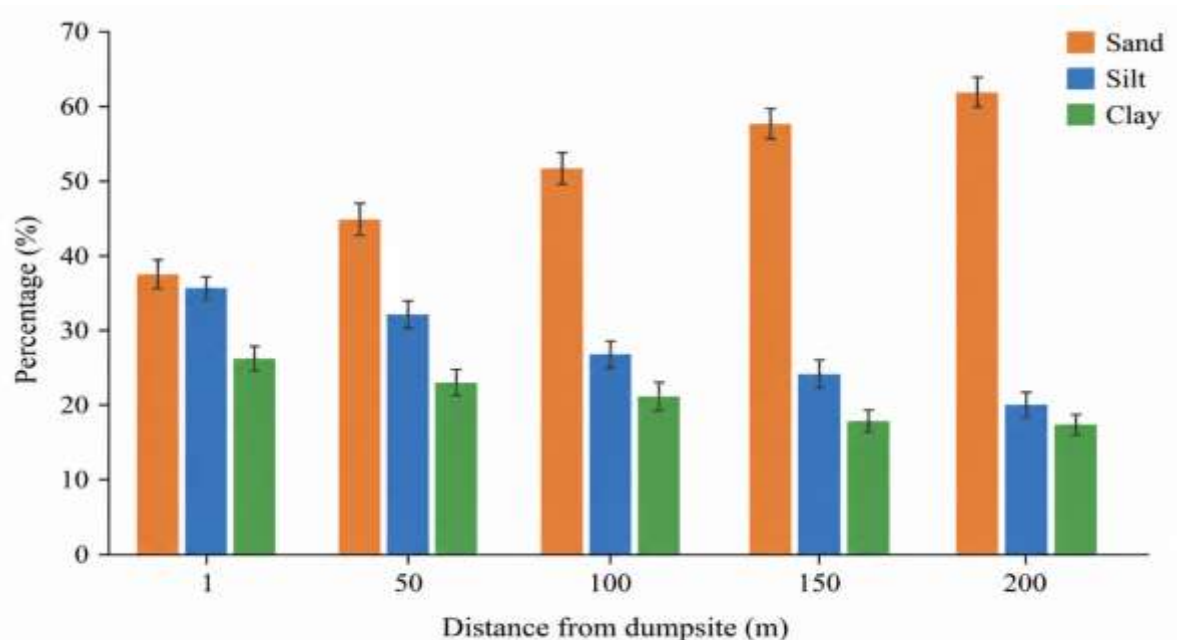


Figure 2: Particle Size Distribution of Soil Samples at Different Distances from the Dumpsite

4.2 Chemical Properties of Soil at the Gboko Rice Mill

The chemical properties of soils at the Gboko rice mill during the dry season of 2021 are presented in Table 3. The pH(H₂O) of the soil was variable and ranged from 7.40 at the dumpsite. The values decreased to 6.80 at 50 m away from the dumpsite to 6.40, 6.20, and 6.00 at 100, 150, and 200 m (control) away from the dumpsite. The pH(KCl) varied from 6.90 at the dumpsite and progressively decreased to 6.70, 6.30, 6.12, and 5.90 at 50, 100, 150, and 200 m (control) away from the dumpsite. Organic carbon content of the soils at the Gboko rice mill varied from 3.30% at the dumpsite to 3.25, 3.17, 3.09, and 2.90% at 50, 100, 150, and 200 m (control) away from the dumpsite. Nitrogen content of the soils also varied from 0.30% at the dumpsite to 0.29, 0.15, 0.14, and 0.10% at 50, 100, 150, and 200 m (control) away from the dumpsite. The sulphur content of this soil also varied from 0.40 mg kg⁻¹ at the dumpsite to 0.30, 0.20, 0.19, and 0.15 mg kg⁻¹ at 50, 100, 150, and 200 m (control) away from the dumpsite.

Bray-1 P content of the soils ranged from 3.70 mg kg⁻¹ at the dumpsite to 3.62, 3.50, 3.41, and 3.21 mg kg⁻¹ at 50, 100, 150, and 200 m away from the dumpsite. The iron content of the rice mill soils was found to be 0.61 mg kg⁻¹ at the dumpsite. At 50 m away from the dumpsite, this value increased to 0.68, 0.69, 0.72, and 0.77 mg kg⁻¹ at 50, 100, 150, and 200 m away from the dumpsite. Aluminium content of the soils was 0.43 mg kg⁻¹ at the dumpsite and progressively increased to 0.44, 0.46, 0.47, and 0.52 mg kg⁻¹ at 50, 100, 150, and 200 m (control) away from the dumpsite. Cation exchange capacity (CEC) was also variable with a value of 5.92 cmol kg⁻¹ at the dumpsite and progressively decreased to 4.89, 4.25, 4.20, and 4.10 cmol kg⁻¹ at 50, 100, 150, and 200 m (control) away from the dumpsite.

Nitrates concentration in the soils also varied from 0.006 mg kg⁻¹ at the rice mill waste dumpsite and at 50 m away from the dumpsite and decreased to 0.005, 0.004, 0.002, and 0.001 mg kg⁻¹ at 100, 150, and 200 m (control) away from the dumpsite. Sulphate concentration was also variable with a value of 1.01 mg kg⁻¹ at the dumpsite. Phosphate concentration was found to be 2.03 mg kg⁻¹ at the dumpsite and progressively varied to 2.02, 2.00, 1.95, and 1.87 mg kg⁻¹ at 50, 100, 150, and 200 m away from the dumpsite. Base saturation (%) also varied from 93.00% at the dumpsite to 92.00% at 50, 100, 150, and 200 m (control) away from the dumpsite. Electrical conductivity of the soil was also variable and ranged from 0.23 dS m⁻¹ and progressively decreased to 0.22 at 50 m away from the dumpsite, 0.21 at 100 m, and 0.20 dS m⁻¹ at 150 m away from the dumpsite to 0.19 dS m⁻¹ at 200 m (control) away from the dumpsite.

Table 3: Chemical Properties of Soils in Gboko Rice Mill (Dry Season)

Parameter	1 m	50 m	100 m	150 m	200 m (Control)
pH (H ₂ O)	7.40	6.80	6.40	6.20	6.00
pH (KCl)	6.90	6.70	6.30	6.12	5.90
OC (%)	3.30	3.25	3.17	3.09	2.90
N (%)	0.30	0.29	0.15	0.14	0.10
S (mg/kg)	0.40	0.30	0.20	0.19	0.15
Bray-1 P (mg/kg)	3.21	3.41	3.50	3.62	3.70
Ca (cmol/kg)	2.90	2.50	2.30	2.28	2.10
Mg (cmol/kg)	1.72	1.39	1.30	1.27	1.19
K (cmol/kg)	0.72	0.44	0.35	0.33	0.30
Na (cmol/kg)	0.15	0.14	0.12	0.10	0.08
Fe (mg/kg)	0.61	0.68	0.69	0.72	0.77
Al (mg/kg)	0.43	0.44	0.46	0.47	0.52

Parameter	1 m	50 m	100 m	150 m	200 m (Control)
CEC (cmol/kg)	5.92	4.89	4.25	4.25	4.10
NO ₃ (mg/kg)	0.006	0.005	0.004	0.002	0.001
SO ₄ (mg/kg)	1.01	1.00	0.05	0.04	0.02
PO ₄ (mg/kg)	2.03	2.02	2.00	1.95	1.87
ESP (%)	2.50	2.50	2.40	2.30	2.20
BS (%)	93.00	92.00	92.00	92.00	92.00
EC (dS/m)	0.22	0.22	0.21	0.20	0.19

The pH of the soil at this location during the dry season varied from 7.40 to 6.00. Generally, the pH values across the location were higher during the dry season. Dissolution of components of the parent material which may be acid-forming could be responsible for this. Acidity at all locations also increased with increasing distance away from the dumpsite. Decrease in volume of the rice mill solid waste with distance away from the dumpsite could be responsible for this trend as the organic solid waste could have buffered the soils where the wastes are more abundant (Nwite & Azuka, 2019).

Decomposition products of the solid waste which could have been basic in nature could have probably neutralized this acidity. Increasing acidity with distance away from the dumpsite implies that nutrient availability would also decrease with distance away from the dumpsite. Evidence that pH exerts the greatest general influence on plant growth through its effect on nutrient availability had earlier been reported by Foth (1990). Generally, micronutrient and perhaps heavy metal availability increases with decreasing pH, thus the concentration of these metals would likely increase with distance away from the dumpsite.

Interestingly, organic carbon, nitrogen, phosphorus, and sulphur content at all locations decreased with distance away from the dumpsite. The cation exchange capacity of the experimental location also followed the same trend. Foth (1990) had earlier reported that the most favourable range for nitrogen availability is between pH 6 and 8, because this is the most favourable range for the soil microbes that mineralize the nitrogen in organic matter and those organisms that fix nitrogen symbiotically. Maximum phosphorus availability has also been reported to be in the range of pH 7.5 to 6.5. As soil acidity increases, those nutrients show less availability as a result of decreasing CEC and decreased amounts of exchangeable nutrient cations. This trend is observed in all the soils studied. On the contrary, concentration of Fe and Al increased with distance away from the dumpsite. Evidence that iron and manganese availability increase with increasing acidity because of their increased solubility had earlier been reported by Foth (1990). This was the case in the instant study.

The high organic carbon and nitrogen contents at the dumpsite and nearby distances can be attributed to the decomposition of rice mill waste, which is rich in organic matter. Nnabude and Mbagwu (2001) reported similar findings, noting that rice mill waste amendment increased soil organic carbon content. The elevated CEC at the dumpsite reflects the contribution of organic matter to the exchange complex, as organic matter has a high CEC compared to mineral soil components (Brady & Weil, 2015). The high base saturation (93%) at the dumpsite indicates that the exchange complex is dominated by basic cations (Ca²⁺, Mg²⁺, K⁺, Na⁺), which is consistent with the neutral to slightly alkaline pH observed at this location.

The low electrical conductivity values (0.19–0.23 dS m⁻¹) indicate that the soils are not saline and that salt accumulation is not a concern at this location. According to FAO (1994), soils with EC values below 2 dS m⁻¹ are

considered non-saline and suitable for most crops. The slight decrease in EC with distance from the dumpsite suggests that the rice mill waste may have contributed some soluble salts to the soil, but not to an extent that would cause salinity problems.

4.3 Selected Heavy Metal Status of the Experimental Sites

The concentrations of selected heavy metals (Cd, Pb, Cr, Mn, and Zn) in soils at the Gboko rice mill are presented in Table 4. The concentrations of all metals decreased with distance away from the dumpsite, with the highest concentrations recorded at the dumpsite (1 m) and the lowest at 200 m (control).

Table 4: Selected Heavy Metal Status of the Experimental Sites

Distance from Dumpsite (m)	Depth (cm)	Cd	Pb	Cr	Mn	Zn
1	0–30	0.06	0.48	0.08	0.12	0.40
50	0–30	0.04	0.30	0.10	0.12	0.38
100	0–30	0.03	0.27	0.09	0.10	0.27
150	0–30	0.04	0.18	0.04	0.09	0.16
200	0–30	0.03	0.12	0.07	0.06	0.12

The concentration of cadmium (Cd) in soil at the Gboko rice mill dumpsite was 0.06 mg kg^{-1} , which is below the safety limit of 3.0 mg kg^{-1} established by Al-Jaboobi (2014). However, the result showed that the cadmium concentration at the dumpsite was slightly above the permissible limit of 0.03 mg kg^{-1} recommended by the World Health Organization (2004) for agricultural soils. The concentration of Cd decreased to 0.04 mg kg^{-1} at 50 m, 0.03 mg kg^{-1} at 100 m, 0.04 mg kg^{-1} at 150 m, and 0.03 mg kg^{-1} at 200 m (control). This pattern suggests that the rice mill solid waste is a source of cadmium contamination in the soil, although the concentrations are relatively low. Lead (Pb) concentration was highest at the dumpsite (0.48 mg kg^{-1}) and decreased progressively to 0.30, 0.27, 0.18, and 0.12 mg kg^{-1} at 50, 100, 150, and 200 m, respectively. All Pb concentrations were well below the safety limit of 100 mg kg^{-1} (Al-Jaboobi, 2014), indicating that lead contamination is not a significant concern at this location. Chromium (Cr) concentrations ranged from 0.04 to 0.10 mg kg^{-1} , with no clear spatial trend, and were far below the safety limit of 100 mg kg^{-1} . Manganese (Mn) concentrations ranged from 0.06 to 0.12 mg kg^{-1} , well below the safety limit of 2000 mg kg^{-1} . Zinc (Zn) concentrations were highest at the dumpsite (0.40 mg kg^{-1}) and decreased with distance to 0.12 mg kg^{-1} at 200 m, but all values were far below the safety limit of 300 mg kg^{-1} .

The decrease in heavy metal concentrations with distance away from the dumpsite is consistent with the findings of Nwite and Azuka (2019) and Ifejimalu (2018), who reported similar spatial patterns in rice mill waste dump sites in southeastern Nigeria. The gradual decline in metal concentrations with distance reflects the limited mobility of most heavy metals in soil, particularly in neutral to slightly alkaline conditions where they tend to precipitate as insoluble hydroxides, carbonates, or phosphates (Alloway, 1995; Kabata-Pendias, 2011). The relatively elevated concentrations at the dumpsite are attributable to the continuous deposition of rice mill waste, which contains trace amounts of these metals, and their accumulation over time. The finding that Cd concentrations at the dumpsite slightly exceeded the WHO (2004) permissible limit is of concern, given the toxicological significance of cadmium. Cadmium is a non-essential heavy metal that can accumulate in the kidneys and liver, causing renal dysfunction, bone demineralization, and cardiovascular problems (Goyer & Clarkson, 2001). The source of cadmium in rice mill waste may be related to the uptake of cadmium by rice plants from soil, followed by concentration in the husk during milling (Yahaya et al., 2026). Alternatively, cadmium may be introduced through contamination during the milling process or from the machinery used.

The concentrations of heavy metals in soils at the Gboko rice mill were generally lower than those reported in other studies of rice mill waste-affected soils. For example, Yahaya et al. (2026) reported iron concentrations of 10.90–13.60 mg/L and zinc concentrations of 6.90 mg/L in soils around Labana Rice Mill in Birnin Kebbi, Nigeria, which exceeded WHO guidelines. The lower concentrations observed in this study may be attributed to the shorter duration of waste accumulation, differences in the composition of the rice mill waste, or variations in

soil properties that affect metal mobility and retention. The grouped bar chart in figure 3 illustrates the variation in heavy metal concentrations (Cd, Pb, Cr, Mn, and Zn) in soil samples collected at different distances (1 m, 50 m, 100 m, 150 m, and 200 m) from the dumpsite. The results show a general decline in metal concentrations with increasing distance from the dumpsite, with the highest levels recorded at the nearest sampling point (1 m) and the lowest concentrations observed at 200 m. This pattern indicates the influence of rice mill solid waste disposal on surrounding soil contamination, with reduced accumulation as distance from the waste source increases.

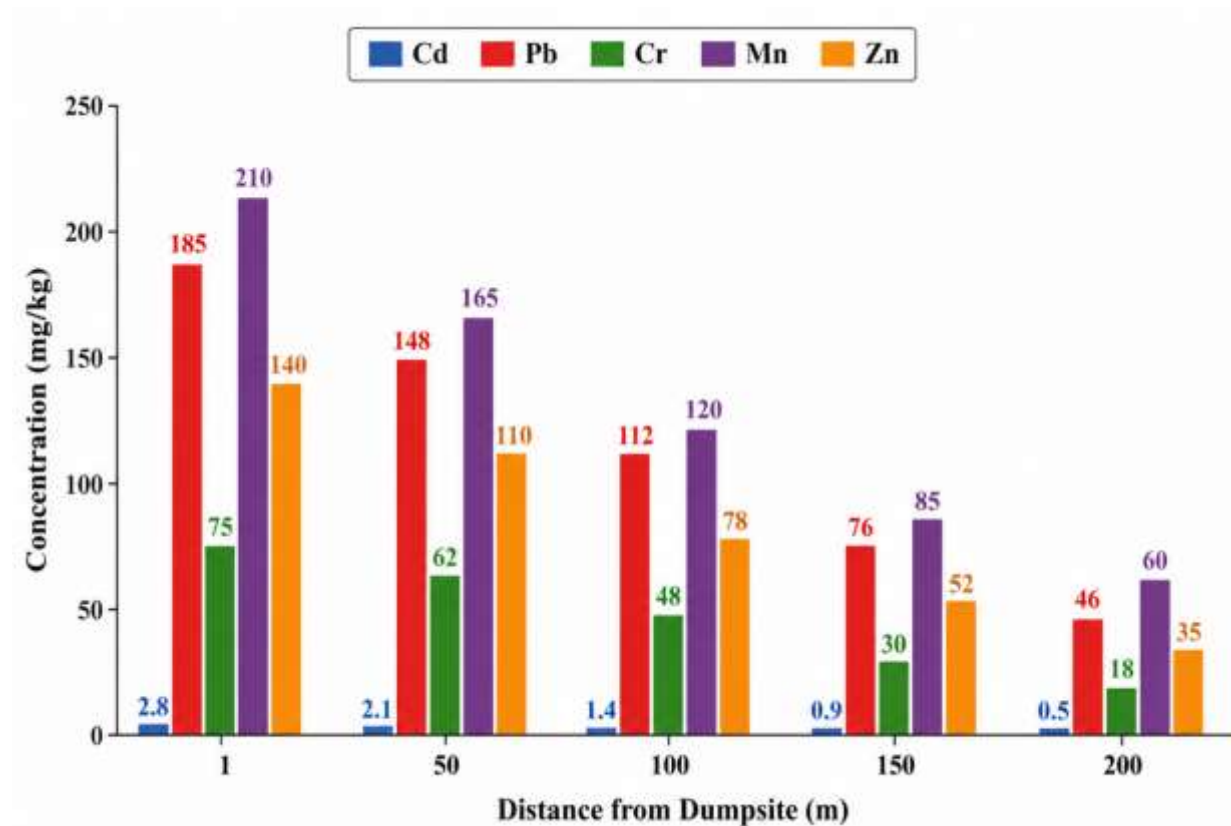


Figure 3: Concentrations of Cd, Pb, Cr, Mn, and Zn in Soils at Different Distances from the Dumpsite

4.4 Comparison with International Standards

The concentrations of heavy metals in soils at the Gboko rice mill were compared with international regulatory limits (Table 5). All metals, except Cd, were below the maximum permissible limits established by Al-Jaboobi (2014) and the World Health Organization (2004). The Cd concentration at the dumpsite (0.06 mg kg^{-1}) exceeded the WHO (2004) limit of 0.03 mg kg^{-1} for agricultural soils but was below the 3.0 mg kg^{-1} limit set by Al-Jaboobi (2014). This discrepancy highlights the variation in regulatory standards for heavy metals in soils and the need for site-specific risk assessment.

Table 5: Heavy Metal Concentrations in Soils Compared with International Standards (mg kg^{-1})

Heavy Metal	Highest Observed Concentration (1 m)	WHO (2004) Limit	Al-Jaboobi (2014) Limit	Status
Cd	0.06	0.03	3.0	Exceeds WHO limit
Pb	0.48	100	100	Within limits

Heavy Metal	Highest Observed Concentration (1 m)	WHO (2004) Limit	Al-Jaboobi (2014) Limit	Status
Cr	0.10	100	100	Within limits
Mn	0.12	—	2000	Within limits
Zn	0.40	300	300	Within limits

The exceedance of the WHO limit for Cd at the dumpsite indicates a potential health risk that warrants further investigation and monitoring. The accumulation of Cd in soils over time through continuous waste deposition could lead to increased Cd uptake by crops grown in the area, potentially entering the food chain and posing health risks to consumers. This finding underscores the need for regular monitoring of heavy metal concentrations in soils around the rice mill and the implementation of appropriate remediation measures where necessary.

4.5 Implications for Soil Quality and Environmental Health

The results of this study have significant implications for soil quality and environmental health in the vicinity of the Gboko rice mill. The elevated organic carbon, nitrogen, phosphorus, and sulphur contents at the dumpsite and nearby distances indicate that rice mill solid waste can serve as a source of organic matter and plant nutrients, potentially improving soil fertility (Nnabude & Mbagwu, 2001; Mbah, 2006). However, the concurrent accumulation of heavy metals, particularly Cd, in these soils raises concerns about the long-term sustainability of this practice.

The decrease in soil pH with distance from the dumpsite (from 7.40 to 6.00) suggests that the decomposition of rice mill waste releases basic cations that neutralize soil acidity near the dumpsite. This liming effect can be beneficial for acid soils, as it improves nutrient availability and reduces Al and Mn toxicity (Foth, 1990). However, the increased acidity at greater distances from the dumpsite may limit nutrient availability and crop productivity, highlighting the need for appropriate soil management practices in areas not directly affected by waste deposition.

The accumulation of Cd in soils at the dumpsite, although below the Al-Jaboobi (2014) limit, exceeds the WHO (2004) guideline, indicating a potential risk to environmental health. Cadmium is a non-biodegradable pollutant that can persist in soils for decades and accumulate in crops, entering the food chain and posing health risks to humans and animals (Goyer & Clarkson, 2001). The remediation of Cd-contaminated soils is therefore essential to protect public health and ensure the safety of agricultural produce from the area.

4.6 Management and Remediation Strategies

Several strategies can be employed to manage heavy metal contamination in soils around the Gboko rice mill. These include:

1. **Source control:** Reducing the deposition of rice mill waste on land through proper disposal and recycling. Rice husk can be used as a fuel source, as a soil amendment after composting, or as a raw material for the production of silica-based products (Nnabude & Mbagwu, 2001).
2. **Phytoremediation:** The use of hyperaccumulator plants to extract heavy metals from contaminated soils. Species such as *Amaranthus hybridus* have been shown to accumulate Cd and other heavy metals in their tissues and could be used for phytoremediation of contaminated sites (Anjembe et al., 2018).
3. **Soil amendments:** The application of organic amendments such as compost, biochar, or lime can reduce the bioavailability of heavy metals by increasing soil pH and complexing metals with organic matter (Nwite & Azuka, 2019). Rice husk ash has been shown to reduce the accumulation of Cd and As in rice (Xiao et al., 2022), and could potentially be used to remediate soils contaminated with these metals.
4. **Monitoring and regulation:** Regular monitoring of heavy metal concentrations in soils, crops, and water around the rice mill is essential to detect contamination early and implement appropriate management measures. Regulatory agencies should enforce limits on heavy metal concentrations in rice mill waste and ensure compliance with safe disposal practices.

5. **Public awareness:** Educating farmers and rice millers about the potential risks of heavy metal contamination and the importance of proper waste management can help reduce the environmental impact of rice milling operations.

5. Conclusion

It was concluded from the foregoing that:

- i. Rice mill solid waste significantly influenced various measurable soil properties in all the experimental locations.
- ii. Soil quality decreased with distance away from the dumpsite, with the highest concentrations of organic carbon, nitrogen, phosphorus, sulphur, and exchangeable bases recorded at the dumpsite and the lowest at 200 m (control).
- iii. Rice mill solid waste contributed to the heavy metal, CEC, salt content, nitrates, phosphates, and sulphates status of soil in the experimental locations.
- iv. The concentration of these pollutants and metals except for Cd was within the WHO/FAO safety limits. The Cd concentration at the dumpsite slightly exceeded the WHO (2004) permissible limit, indicating a potential health risk that warrants further investigation.

6. Recommendations

Based on the findings of this study, the following recommendations are made:

1. **Continuous monitoring** of soil quality indices (pH, organic carbon, nutrients, and heavy metals) is required to avoid contamination of soils within the vicinity of the dumpsites.
2. **Designated areas** should be created by relevant authorities for the disposal of these solid wastes, which to a large extent are an eyesore and a source of environmental pollution.
3. **The solid waste can be composted and recycled** as organic fertilizers and liming material because of its influence on soil fertility and acidity. Proper composting can reduce the volume of waste and produce a valuable soil amendment.
4. **Remediation for Cd** in soils of the studied location would be required to prevent the accumulation of this toxic metal in crops and the food chain. Phytoremediation using hyperaccumulator plants such as *Amaranthus hybridus* could be a cost-effective and environmentally friendly approach.
5. **Further research** should be conducted to evaluate the long-term effects of rice mill waste deposition on soil quality and to develop integrated nutrient management strategies that optimize the beneficial effects of the waste while minimizing the risks of heavy metal contamination.

References

- Al-Jaboobi, M. (2014). *Assessment of heavy metal contamination in soils and vegetables irrigated with wastewater in Yemen* [Doctoral thesis, Universiti Putra Malaysia].
- Alloway, B. J. (1995). *Heavy metals in soils* (2nd ed.). Blackie Academic & Professional.
- Anjembe, B. C., Gesa, T. R., & Ibrahim, N. B. (2018). Effect of fertilizer sources on heavy metal accumulation in soils and quality of Amaranth (*Amaranthus hybridus*) grown in Makurdi, Nigeria. *Nigerian Journal of Soil Science and Tillage Research*, 4, 25–35.
- Bouyoucos, G. J. (1951). A recalibration of the hydrometer method for making mechanical analysis of soils. *Agronomy Journal*, 43(9), 434–438.
- Brady, N. C., & Weil, R. R. (1999). *The nature and properties of soils* (12th ed.). Prentice-Hall.
- Brady, N. C., & Weil, R. R. (2015). *The nature and properties of soils* (14th ed.). Pearson Education.
- Bremner, J. M., & Mulvaney, C. S. (1982). Nitrogen—Total. In A. L. Page, R. H. Miller, & D. R. Keeney (Eds.), *Methods of soil analysis: Part 2. Chemical and microbiological properties* (2nd ed., pp. 595–624). American Society of Agronomy.
- Das, D. K. (2015). *Introductory soil science*. Kalyani Publishers.
- Duncan, D. B. (1955). Multiple range and multiple F tests. *Biometrics*, 11(1), 1–42.
- European Union. (2002). *Council Directive 86/278/EEC on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture*. Official Journal of the European Communities.

- FAO. (1994). *Water quality for agriculture* (FAO Irrigation and Drainage Paper 29, Rev. 1). Food and Agriculture Organization of the United Nations.
- Foth, H. D. (1990). *Fundamentals of soil science* (8th ed.). John Wiley & Sons.
- Goyer, R. A., & Clarkson, T. W. (2001). Toxic effects of metals. In C. D. Klaassen (Ed.), *Casarett and Doull's toxicology: The basic science of poisons* (6th ed., pp. 811–867). McGraw-Hill.
- Ifejimalu, A. C. (2018). Effects of rice mill wastes on soil properties in a rice-producing state of south-eastern Nigeria. *Nigerian Journal of Soil Science*, 28(2), 91–221.
- Kabata-Pendias, A. (2011). *Trace elements in soils and plants* (4th ed.). CRC Press.
- Karlen, D. L., Mausbach, M. J., Doran, J. W., Cline, R. G., Harris, R. F., & Schuman, G. E. (1997). Soil quality: A concept, definition, and framework for evaluation. *Soil Science Society of America Journal*, 61(1), 4–10.
- Laoye, B. J., Adebayo, A. O., & Ogunleye, O. O. (2025). Heavy metal contamination: Sources, health impacts, and sustainable mitigation strategies with insights from Nigerian case studies. *Environmental Science and Pollution Research*, 32(15), 18567–18589.
- Larson, W. E., & Pierce, F. J. (1994). The dynamics of soil quality as a measure of sustainable management. In J. W. Doran, D. C. Coleman, D. F. Bezdicek, & B. A. Stewart (Eds.), *Defining soil quality for a sustainable environment* (pp. 37–51). Soil Science Society of America.
- Mbah, C. N. (2006). Influence of organic wastes on plant growth parameters and nutrient uptake by maize (*Zea mays* L.). *Nigerian Journal of Soil Science*, 16, 104–108.
- Njoku, C., & Mbah, C. N. (2012). Effect of wastes on selected soil properties in Abakaliki southeastern Nigeria. *International Journal of Plant & Soil Science*, 1(3), 178–188.
- Nnabude, P. C., & Mbagwu, J. S. C. (2001). Physicochemical properties and productivity of a Nigerian Typic Haplustult amended with fresh and burnt rice mill wastes. *Bioresource Technology*, 76(3), 265–272.
- Nwite, J. N., & Azuka, C. V. (2019). Impact of rice mill wastes dump on soil physico-chemical properties in Abakaliki, southeastern, Nigeria. *Elsevier Science*.
- Odeh, A. A., Alwadood, J. A., Ihenacho, M. N., Kopteer, E. P., Aniya, U., John, J. A., Nwagwu, N. G., Abdullahi, S. K., Oriola, H. I., Aaron, V., Jackson, E. R., Tukur, K. A., Adebo, K. O., Nweke, C. A., Ikediashi, T., Ikwuka, A. C., & Amodu, P. O. (2024). A GIS-based analysis of heavy metals around Otukpo rice mill in Benue state. *World Journal of Advanced Research and Reviews*, 22(1), 1025–1031.
- Odoh, R. (2014). Assessment of soils in the vicinity of rice mill industry, Otukpo, Benue State for potential heavy metal contaminations. *Semantic Scholar*.
- Olatunji, O., & Ayuba, S. A. (2011). Effect of combined applications of poultry manure and NPK 20-20-10 fertilizer on soil chemical properties and yield of maize (*Zea mays* L.). *Proceedings of the 35th Annual Conference of the Soil Science Society of Nigeria*, 145–154.
- Onakpa, M. M., Njan, A. A., & Kalu, O. C. (2018). A review of heavy metal contamination of food crops in Nigeria. *Annals of Global Health*, 84(3), 488–494.
- Rakshit, A., Raha, P., & Bhadoria, P. S. (2015). *Principles of soil science*. Kalyani Publishers.
- Rakshit, A., Raha, P., & Bhadoria, P. S. (2017). *Principles of soil science* (2nd ed.). Kalyani Publishers.
- Seybold, C. A., Mausbach, M. J., Karlen, D. L., & Rogers, H. H. (2014). Quantification of soil quality. In R. Lal, J. M. Kimble, R. F. Follett, & B. A. Stewart (Eds.), *Soil processes and the carbon cycle* (pp. 387–404). CRC Press.
- Titler, K. G. (1986). Essential and toxic heavy metals in soils and their ecological relevance. *Transactions of the XII Congress of the International Society of Soil Science*, 1, 29–44.
- Udo, E. J., Ibia, T. O., Ogunwale, J. A., Ano, A. O., & Esu, I. E. (2009). *Manual of soil, plant and water analysis*. Sibon Books.
- Uguru, B. N., Mbah, C. N., & Njoku, C. (2015). Effect of organic wastes on selected soil physical properties and crop yield in Abakaliki, Southeastern Nigeria. *Global Advanced Journal of Agricultural Science*, 4(12), 2315–5094.
- Umar, B. A., Kawuwa, B., Dewa, A. U., Muhammad, S. L., & Aminu, R. S. (2025). Assessment of heavy metal levels in vegetables grown on abandoned refuse dumpsite soil and associated health risks in Mubi Metropolis, Adamawa State, Nigeria. *ASRIC Journal on Natural Sciences*, 5(1), 45–58.
- United States Environmental Protection Agency. (1999). *Guide to Part 503 rule*. USEPA.

- USDA. (2001). *Guidelines for soil quality assessment in conservation planning*. United States Department of Agriculture, Natural Resources Conservation Service, Soil Quality Institute.
- Walkley, A., & Black, I. A. (1934). An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Science*, 37(1), 29–38.
- WHO. (2004). *International standards for drinking water*. World Health Organization.
- Wuana, R. A., & Okieimen, F. E. (2011). Heavy metals in contaminated soils: A review of sources, chemistry, risks and best available strategies for remediation. *ISRN Ecology*, 2011, Article 402647.
- Xiao, Y., Li, Y., & Zhang, Y. (2022). Regulation of rhizosphere microenvironment by rice husk ash for reducing the accumulation of cadmium and arsenic in rice. *Journal of Environmental Sciences*, 136, 1–10.
- Yahaya, T., Bello, S., Izuafa, A., Inuwa, F., Boku, U. I., & Nathaniel, J. (2026). Heavy metal contamination, physicochemical properties, and environmental health risks of soils affected by rice mill effluents in Birnin Kebbi, Nigeria. *Journal of Environmental Science, Health & Sustainability*, 2(2), 174–186.

How to Cite the Article: Gesa, T. R., Apuu, J., & Surma, S. K. (2026). Influence of rice mill solid waste on soil quality in Gboko Rice Mill of Benue State, Nigeria. *International Journal of Engineering, Science, and Environmental Research*, 2(1), 381–382.