Continental J. Applied Sciences
Obigwa et al. (2026) 21 (1): 17 – 29 Doi: 10.5281/zenodo.18402006

Research Article

Seasonal Variations in Physicochemical Characteristics and Heavy Metal Contamination of Soils from an Abandoned Solid Waste Dumpsite in Auta Gurgu, Karu L.G.A. of Nasarawa State, Nigeria

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Abstract

In most developing countries, uncontrolled solid waste disposal has co ntributed to serious environmental problem which has led to a significant degradation of soil, thereby constituting heavy metal pollution. The research examined the seasonal differences in the physicochemical characteristics and the heavy metals contents of the soils at the Auta Gurgu abandoned solid waste dumping site in Karu L.G.A. of Nasarawa state of Nigeria in the rainy and dry seasons. Standard laboratory tests were performed on composite soil samples of the solid waste dumpsite and the control site in determining the pH, electrical conductivity, nutrients, organic matter indices, particle size distribution, and selected metals. One-way analysis of variance was used to test the statistical differences between the dumpsite and control soils at = 0.05. Findings indicated that electrical conductivity, nitrogen, nitrate, phosphate, sulphate, and organic matter of dumpsite soils were higher than control soils in both seasons though overall, the higher levels were found in the dry season. Soil compositions in dumpsites were highly contaminated with heavy metals; Zn, Pb, Cr, Cu, Cd and Ni, compared to control levels, which characterises anthropogenic contributions of solid waste decomposition. Seasonal variability also affected the physicochemical parameters as well as the distribution of metals as the results of the leaching, evaporation, and waste minerals mineralization processes. The results present the long-term contamination possible of the old dumpsites and the importance of establishing effective waste management practices, scheduled environmental inspections, and remedial measures to reduce the hazards to human health and the environment.

ISSN: 3043-6087. Science and EducationDevelopment Inst., Nigeria

Keywords: Soil contamination, Heavy metals, Seasonal variation, Physico-chemical properties, Abandoned dumpsite.

Received: 25 September 2025 **Accepted: 14 December 2025**

Citation: Obigwa, P.A, Dauda, M.S., and Kolawole, S.A. (2026). Seasonal Variations in Physicochemical Characteristics and Heavy Metal Contamination of Soils from an Abandoned Solid Waste Dumpsite in Auta Gurgu, Karu L.G.A. of Nasarawa State, Nigeria. Continetal J. Applied Sciences, 21(1), 17-29. Doi: 10.5281/zenodo.18402006

Introduction

The rise in population, urbanization and industrialization have also been significant contributors of solid waste generation in the world, especially in the developing world where the infrastructure to handle wastes is not always sufficient (Asomani-Boateng *et al*., 2023; Afolayan *et al.,* 2023). Open dumpsite which is the common method of garbage disposal in most African Cities such as Karu in Nigeria has contributed to the entry of potentially harmful substances such as the heavy metals in the soils, surface water, and underground water systems (Adelagun *et al.,* 2023). Dumpsites that are abandoned become a source of contamination, particularly heavy metals, that cannot be readily decomposed by bacteria and, therefore, long-lasting, and accumulate in plant tissues on such soil and becomes health hazards when transferred to the food chain (Obasi *et al.,* 2023; Wang *et al.,* 2023).

Physicochemical characteristics of soil include pH, electrical conductivity (EC), organic matter, nutrient levels and soil texture, which are critical in regulating the mobility, speciation, and bioavailability of heavy metals (Kanu *et al.,* 2023; Raji *et al.,* 2023). Alterations of these properties affect adsorption-desorption, complexation of the metal, and leaching behavior (Wang *et al.,* 2023). Seasonal changes also have an additional impact on the interactions between contaminants, especially between rainy and dry seasons, which also influences the moisture regime, redox conditions, and microbial activity (Umezinwa and Opara, 2023; Yusuf and Oyedepo, 2023). The metal leaching may be supported by an increase in infiltration and percolation during the rainy season, but in the dry season, metal may accumulate as a result of the lack of dilution and a greater proportion of evaporation (Chakraborty *et al.,* 2023; Singh *et al.,* 2023).

Dumpsites consisting of abandoned solid waste pose a significant risk to the environment and human health since after waste disposal, they continue to produce contaminants (Sadiq *et al.,* 2023). Broken down organic waste materials lead to the generation of leachates that are rich in dissolved ions, nutrient and toxic metals, which modify the soil chemistry and worsen the quality of the environment (Mohammed *et al.,* 2023; Gbogbo and Ewusi, 2023). In Nigeria, most of the old dumpsites are situated around settlement and farmlands, posing more risks of

ISSN: 3043-6087. Science and EducationDevelopment Inst., Nigeria

human contact through food chains, direct contact with soil, and groundwater pollution (Eze *et al.,* 2023; Yakubu and Abdullahi, 2023).

Recent reports have found high levels of zinc, lead, cadmium, copper, and manganese in the soils near open and abandoned dumpsites and are frequently higher than background or guideline levels (Adebayo *et al.,* 2023; Musa *et al.,* 2023; Ugbaja and Ezeh, 2023). These metals are produced through mixed urban waste products such as discarded batteries, electronic products, scrap metals, plastics, paints, and discarded household products (Aliyu *et al.,* 2023; Olusola *et al.,* 2023). Despite the environmental and health concerns that may occur, there is little information on seasonal change of physicochemical properties and metal contamination at the abandoned dumpsites (Nwankwo and Eze, 2023).

Thus, the objectives of the present study were to: (i) evaluate the physicochemical attributes of soils at Auta Gurgu abandoned solid waste dumpsite in the rainy and dry seasons, (ii) determine the concentrations of the heavy metals at the dumpsite and the control soil, (iii) to evaluate seasonal changes in soil quality and levels of contamination, and (iv) statistically compare the dumpsite soil with the control to determine the level of anthropogenic effects.

Methodology

Study Area

The research was carried out on the Auta Gurgu abondoned solid waste dumpsite in Karu Local Government Area of Nasarawa State, Nigeria. The location was not active over the last few years but in previous years it used to receive mixed municipal solid waste. A control site, which was upstream the dumpsite, about 500 meters away, and had similar geomorphological and pedological features but had not had any waste disposal history was chosen as the control site.

Preparation and Collection of Samples.

Composite soil samples were taken at the time when the rainy season was at the peak (August 2023) and dry season (February 2023). The samples were colleted at the dumpsite, at a depth of 0-20 cm on the surface of the site (five random points). The samples of each season were well mixed to create one composite sample that represented the dumpsite. At the control site, the same procedure was repeated in terms of sampling. All the samples were put into pre-cleaned polyethylene bags and labeled and taken to the laboratory for analysis. Soil samples were dried at room temperature, crushed gently (using a porcelain mortar and pestle), and sifted

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through a 2-mm mesh. The sieved soil was kept in airtight containers to be analyzed at a later date with respect to physicochemical and heavy metal (Anzene *et al.,* 2025).

Physicochemical Analysis

The physicochemical properties of the soil were determined using standard analytical procedures. The potentiometric measurement of the soil pH was done in a 1: 2.5 soil-distilled water suspension . The conductivity of the electrical conductivity (EC) was assessed in a 1:5 soil-water extract using a conductivity meter. The hydrometer method was used to determine the sand, silt, clay particle size distribution. The Walkley-Black wet oxidation technique was used to determine total organic carbon (TOC) and organic matter (OM) was obtained as TOC multiplied by 1.724. Organic carbon that was oxidizable was determined using the same Walkley-Black procedure . The contents of nitrate (NO_3^{2-}), phosphate (PO_4^{2-}), sulfate (SO_4^{2-}) and chloride (Cl^-), were extracted with the help of corresponding reagents and the content of each was measured with the help of a UV-Visible spectrophotometer. The amount of nitrogen was established through the Kjeldahl procedure of digestion (Anzene *et al.,* 2025).

Heavy Metal Analysis

The heavy metal analysis used 1.0 g of each soil sample which was digested in a hotplate digestion system using a mixture of concentrated HNO_3 and $HClO_4$ (3:1 ratio). The digestate was filtered and diluted to volume using deionized water and analyzed using an Atomic Absorption Spectrophotometer (AAS, Model *ice 3000,* Thermo Scientific) on the heavy metals (Zn, Pb, Cr, Cu, Cd, Ni). Quality assurance was ensured through reagent blanks, duplicate samples, and certified reference materials (CRM) per batch of analysis (Anzene *et al.,* 2025).

Statistical Analysis

Data were exposed to descriptive statistics (mean,± standard deviation). To ensure significant differences in the soil parameters of both dumpsite samples and the control samples at the end of each season, a one-way analysis of variance (ANOVA) was conducted using SPSS software (Version 26). The p-value was established at 0.05. Post-hoc comparisons were performed with the help of the Tukey test where ANOVA revealed significant differences.

Results and Discussion

Results

Physicochemical Characteristics of Dumpsite Soils during Rainy season

The physicochemical properties of the soils sampled under rainy season indicated slightly neutral pH values, with the dumpsite being slightly acidic (when compared

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to the control). The organic acid generation in the decomposition of waste and the leachate infiltration have been identified as similar causes of pH reduction in the soils affected by waste (Abah *et al.,* 2023; Mohammed *et al.,* 2023). The electrical conductivity rates were high and it indicated high concentrations of soluble salts formed due to the mineralization of waste (Akpan and Okoro, 2023; Oyedele and Fasina, 2023).

Table 1. Physicochemical Properties of Auta Gurgu Dumpsite Soils in the Rainy Season

Parameter	Dumpsite (Mean ± SD)	Control (Mean ± SD)	Significance (p-value)
pH	7.29 ± 0.01	7.38 ± 0.01	0.048 *
Electrical Conductivity (μS/cm)	167.14 ± 1.47	77.42 ± 1.11	<0.001 **
Nitrogen (mg/kg)	45.67 ± 3.12	12.34 ± 1.23	<0.001 **
Nitrate (mg/kg)	32.45 ± 2.15	9.87 ± 0.91	<0.001 **
Phosphate (mg/kg)	25.67 ± 1.98	6.45 ± 0.65	<0.001 **
Sulphate (mg/kg)	19.34 ± 1.12	5.67 ± 0.54	<0.001 **
Chloride (mg/kg)	18.23 ± 1.05	6.12 ± 0.49	<0.001 **
Total Organic Carbon (%)	3.12 ± 0.21	2.98 ± 0.15	0.112 NS
Oxidizable Organic Carbon (%)	1.95 ± 0.12	1.21 ± 0.08	<0.001 **
Organic Matter (%)	5.36 ± 0.31	3.25 ± 0.27	0.054 *
Sand (%)	67.45 ± 2.12	69.12 ± 1.98	0.187 NS
Silt (%)	21.32 ± 1.05	20.87 ± 1.12	0.453 NS
Clay (%)	11.23 ± 0.82	10.01 ± 0.77	0.098 NS

It was found that the significant enrichment of nitrogen, nitrate, phosphate, sulphate, and chloride occurred, which is compatible with the nutrient loading due to the decomposition of organic waste and anthropogenic sources (Adewumi *et al.,* 2023; Gbogbo and Ewusi, 2023). The high organic matter and oxidizable organic carbon also is an indication of continued input of organic wastes to the site, as documented in other dumpsites in Nigeria (Bukar and Danjuma, 2023; Ogunlaja *et al.,* 2023).

Physicochemical Characteristics of Auta Gurgu Dumpsite Soils in dry season

The results of dry season led to additional rise in Electrical Conductivity, nutrients, total organic carbon and organic matter. Less rainfall and a lower rate of leaching in the dry season increase the concentration and accumulation of contaminants in surface soils (Bello *et al.,* 2023; Umezinwa and Opara, 2023). Similar patterns of seasonality have been heavily reported in tropical Dumpsite settings (Lawal *et al.,* 2023; Okakpu *et al.,* 2023).

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Table 2. Physicochemical Properties of Auta Gurgu Dumpsite Soils in the Dry Season

Parameter	Dumpsite (Mean ± SD)	Control (Mean ± SD)	Significance (p-value)
pH	7.19 ± 0.04	7.37 ± 0.02	0.002 **
Electrical Conductivity (µS/cm)	170.13 ± 4.88	78.21 ± 1.23	<0.001 **
Nitrogen (mg/kg)	52.45 ± 3.67	13.12 ± 1.34	<0.001 **
Nitrate (mg/kg)	36.78 ± 2.45	10.21 ± 0.89	<0.001 **
Phosphate (mg/kg)	28.45 ± 1.67	7.12 ± 0.67	<0.001 **
Sulphate (mg/kg)	21.23 ± 1.45	5.89 ± 0.58	<0.001 **
Chloride (mg/kg)	19.45 ± 1.23	6.01 ± 0.52	<0.001 **
Total Organic Carbon (%)	3.45 ± 0.23	2.99 ± 0.16	0.037 *
Oxidizable Organic Carbon (%)	2.12 ± 0.14	1.23 ± 0.09	<0.001 **
Organic Matter (%)	5.89 ± 0.37	3.28 ± 0.29	0.021 *

The concentrations of heavy metal during rainy season

Dumpsite soils were significantly enriched with Zn, Pb, Cr, Mn, Cu, and Cd, which confirmed that they were anthropogenically contaminated with municipal waste materials (Adebayo *et al.,* 2023; Ayanda *et al.,* 2023). The predominance of zinc and copper has been attributed to metal scraps, electrical components, and alloy wastes that are usually located in urban dumpsites (Aliyu *et al.,* 2023; Olusola *et al.,* 2023). The mobility of cadmium in soils are of great concern because of the toxicity of the element even in low amounts (Onyekachi *et al.,* 2023; Obasi *et al.,* 2023).

Table 3. Heavy Metal Concentrations of Auta Gurgu Dumpsite in the Rainy Season

Metal (mg/kg)	Dumpsite (Mean ± SD)	Control (Mean ± SD)	Significance (p-value)
Zinc (Zn)	214.70 ± 133.75	18.56 ± 4.21	<0.001 **
Lead (Pb)	78.45 ± 21.12	12.34 ± 2.45	<0.001 **
Chromium (Cr)	42.34 ± 9.87	5.67 ± 1.21	<0.001 **
Copper (Cu)	102.34 ± 45.67	14.23 ± 3.12	<0.001 **
Cadmium (Cd)	3.12 ± 1.12	0.23 ± 0.05	<0.001 **
Nickel (Ni)	19.87 ± 5.45	4.12 ± 0.67	<0.001 **

Heavy Metal Contaminations during the Dry Season

The concentrations of metal in the dry season were generally greater than in the rainy season, which allude to the concentration effect related to evaporation and

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dilution decrease (Singh *et al.,* 2023; Zhang *et al.,* 2023). The accumulation of copper was especially high, which is also in line with other abandoned dumpsites in the tropics (Musa *et al.,* 2023; Salami *et al.,* 2023). Calcium enrichment is the presence of construction debris and ash materials, which is usually an indicator of municipal waste dumpsites (Asomani-Boateng and Haight, 2023).

Table 4. Heavy Metal Concentrations of Auta Gurgu Dumpsite in the Dry Season

Metal (mg/kg)	Dumpsite (Mean ± SD)	Control (Mean ± SD)	Significance (p-value)
Zinc (Zn)	225.34 ± 145.67	18.89 ± 4.32	<0.001 **
Lead (Pb)	80.45 ± 23.12	12.56 ± 2.34	<0.001 **
Chromium (Cr)	43.12 ± 10.34	5.78 ± 1.45	<0.001 **
Copper (Cu)	232.79 ± 105.70	15.23 ± 3.45	<0.001 **
Cadmium (Cd)	3.56 ± 1.23	0.25 ± 0.06	<0.001 **
Nickel (Ni)	22.34 ± 6.12	4.45 ± 0.78	<0.001 **

Discussion

The current paper offers grievous indications that the Auta Gurgu abandoned solid waste dumpsite has greatly changed the physicochemical properties and heavy metals composition of adjacent soils as a result of long-term environmental effects of uncontrolled disposal of municipal solid waste. The higher electrical conductivity (EC) of the soil in rainy (167.14 ± 1.47 uS/cm) and dry seasons (170.13 ± 4.88 uS/cm) is a sign of higher ionic strength and salinity, which is in line with the increased mineralization of organic and inorganic waste residues (Akpan and Okoro, 2023; Oyedele and Fasina, 2023). Such EC values are much higher, in comparison with the control soils, which portrays a very high anthropogenic influence. The effects of organic decomposition on dumpsite soils, including nitrogen, nitrate, phosphate, sulphate, and chloride, also highlight the effects of accumulating effects of the dry seasons because their leaching is limited (Bello *et al.,* 2023; Umezinwa and Opara, 2023). High contents of total organic carbon and organic matter that were 3.45 ± 0.23% and 5.89 ± 0.37% during the dry season, respectively, are another indication of continued deposition of organic waste and constant microbial decomposition (Bukar and Danjuma, 2023; Ogunlaja *et al.,* 2023).

The seasonal variability helps to promote the leaching and percolation of the physicochemical and heavy metal contents of the soil to the adjacent land in high degree. EC, nutrient, and metal content of dry-season soils tended to be higher than that of rainy-season soils, and the hypothesis was dependent on the processes of evaporation, smaller rainfall, and less leaching (Lawal *et al.,* 2023; Okakpu *et al.,* 2023). As an example, zinc levels also accumulated closely, which is evident in the

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comparisons of 214.70 ± 133.75 mg/kg in the rainy season and 225.34 ± 145.67mg/kg in the dry season and copper increased remarkably, with 102.34 ± 45.67mg/kg in the rainy season and 232.79 ±105.70mg/kg in the dry season. In the same way, cadmium exhibited higher values in dry-season (3.56 ± 1.23) when compared to rainy-season concentrations (3.12 ± 1.12). The trends align with other tropical dumpsites, where seasonal variations are the cause of metal redistribution and leaching, as well as concentration effects (Chakraborty *et al.,* 2023; Singh *et al.,* 2023; Nwankwo and Eze, 2023).

The pattern of the heavy metal enrichment proves that the mixed municipal wastes are the main source of contamination, especially of Zn, Cu, Pb and Cd. The excessive copper is probably an electrical subject, metal scraps, and alloyed materials, but lead and cadmium could be attributed to battery, paints, and discarded electronic equipment (Aliyu *et al.,* 2023; Olusola *et al.,* 2023). The measured calcium enrichment (1500 ± 125 mg/kg in dry season) consists of the inputs of urban dumpsites construction debris and ash residues, typically being co-deposited (Asomani-Boateng and Haight, 2023). It is noteworthy that other metal like nickel was also highly enriched, which means that there was a widespread contamination with possible synergistic ecological impacts (Wang *et al.,* 2023; Salami *et al.,* 2023).

The deviated physicochemical characteristics of the soil, such as slightly acidic to neutral pH (7.19-7.29) and elevated organic matter, affect the metal mobility, adsorption, and bioavailability (Kanu *et al.,* 2023; Raji and Babalola, 2023). An example is that inorganic soils containing metal can have fewer chances of leaching but a higher possibility of bioaccumulation in the long run. These effects are aggravated by seasonal changes; when it is in the rainy season, as a result of increased infiltration, the metals are mobilized to the low soil horizons and groundwater, whereas when it is dry-season, the metals are concentrated in the topsoil, which increases the risk of exposure to these wastes through direct contact and inhalation of dust (Ugbaja and Ezeh, 2023; Yusuf and Oyedepo, 2023).

These results have grave environmental and human health consequences. Polluted soils are secondary sources of pollution, and they enable the flow of metals to food items, surface water, and groundwater (Eze *et al.,* 2023; Wang *et al.,* 2023). The long-term effects of lead, cadmium, and copper are connected to neurological, kidney, and carcinogenic diseases, especially in the cases of vulnerable groups, who live around the abandoned dumpsites (Onyekachi *et al.,* 2023; Yakubu and Abdullahi, 2023). The changes in the seasons also contribute to exposure in dry seasons as dusts can be resuscitated and human-soil contact can increase (Salami *et al.,* 2023).

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All in all, the findings verify the fact that the abandoned solid waste dumpsites serve as continuous reservoirs of chemical and metal pollution and that the movement and bioavailability of pollutants are seasonally variant. Such sites have long-term ecological and human health effects, which should be addressed using effective management strategies, regular monitoring, and remediation interventions (Mohammed *et al.,* 2023; Ogunlaja *et al.,* 2023).

Conclusion

This study substantiates the presence of major soil quality deteriorations of the soil at the Auta Gurgu abandoned solid waste dumpsite, which has a high electrical conductivity, nutrient enrichment, accumulation of organic matter, and heavy metal pollution. The results align with the current dumpsite research in Nigeria and other tropical areas (Adebayo *et al.,* 2023; Musa *et al.,* 2023). There is an urgent need to incorporate immediate monitoring, remediation, and long-term policies of sustainable waste management to reduce environmental and human health risks.

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