African Multidisciplinary Journal of Sciences and Artificial Intelligence

ISSN : 3434-9871

Index: Harvard, Boston, Sydney University, Dimensions, Lens, ResearchGet Scilit, Semantic, Google Scholar, Base etc

https://doi.org/10.58578/AMJSAI.v2i2.5341

The Impact of Industrial Effluent Discharge on the Physicochemical Characteristics of Agricultural Soil

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Article Info:

Submitted:	Revised:	Accepted:	Published:
Mar 5, 2025	Mar 22, 2025	Apr 2, 2025	Apr 7, 2025

Abstract

This study investigates the effect of agricultural industrial effluent discharge on soil and crops. Soil and crop samples from agricultural fields irrigated with industrial effluent were collected between August 2024 and January 2025. The samples were analysed for heavy metals, including Zinc, Copper, Iron, Lead, Manganese, Cadmium, and Chromium, using standard analytical methods. Data were processed using simple descriptive statistics with Microsoft Excel. Results indicated that Zinc concentrations in crops from Farms 3 to 5 ranged from 0.08 to 0.3 mg/kg, within the WHO/FAO safe limit of 0.60 mg/kg. However, crop samples from Farms 1 and 2 exceeded the WHO/FAO permissible Zinc limit. The concentrations of Copper, Zinc, Iron, and Cadmium in the crops were generally within the WHO permissible levels. The accumulation of heavy metals in crops followed the order: Potatoes, Guinea corn, Garden Egg, Maize and Okra. The findings suggest that the consumption of crops from Farms 1 and 2 could pose significant health risks. The study recommends treating industrial effluent before discharge to mitigate potential health hazards.

Keywords: Industrial Wastewater, Agricultural Produces, Soil, Heavy Metals

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INTRODUCTION

Industries have been directly linked to environmental degradation and pollution over the last forty years through numerous ecological and human disasters (Smith, 2020; Johnson & Lee, 2019). Due to increasing industrialization in residential areas, effluent water contains various environmentally harmful elements (Brown et al., 2021). The use of untreated wastewater for growing vegetables in agricultural soils has become a significant concern (Williams, 2018).

The expansion of manufacturing industries has led to increased production of consumer goods, but it has also resulted in significant waste generation. Effective management of industrial waste is crucial to minimize environmental pollution. However, many manufacturing companies often overlook the comprehensive evaluation of their waste treatment facilities, leading to inadequate handling of waste through essential processes such as sedimentation, sand filtration, oil and grease traps, and gaseous emission precipitators. In Nigeria, certain industrial entities continue to dispose of their waste irresponsibly, releasing solid, liquid, and gaseous byproducts into the environment without adequate treatment. This practice poses significant environmental and health risks, as hazardous substances can contaminate soil, water, and air.

Notably, some farmers have been observed diverting industrial wastewater for irrigation purposes. This water often contains elevated levels of nutrients such as potassium, nitrogen, and phosphorus, which can promote plant growth. However, the use of untreated industrial wastewater in agriculture is fraught with risks, as it may also contain harmful chemicals and heavy metals that can accumulate in crops, posing health hazards to consumers and degrading soil quality over time. The National Environmental Standards and Regulations Enforcement Agency (NESREA, 2025) is responsible for enforcing environmental laws and ensuring compliance with waste management standards in Nigeria. Despite these regulatory frameworks, challenges persist in effectively managing industrial waste, necessitating more stringent enforcement and the adoption of sustainable waste treatment practices by industries. The encroachment of industrial activities into residential areas has led to the release of various environmental pollutants into effluent water. This issue becomes particularly concerning when untreated effluent is used to irrigate vegetable crops in agricultural soils, posing significant risks to both human health and the environment. Industrial effluents frequently contain contaminants such as heavy metals,

organic compounds, and nutrients like nitrogen and phosphorus. When these substances accumulate in soils and crops, they pose potential health hazards to consumers. For instance, the application of sewage sludge as fertilizer has been shown to increase soil phosphorus levels and salinity, adversely affecting plant growth and soil health.

The practice of using wastewater and industrial effluents for irrigating agricultural lands is increasing, particularly in peri-urban areas of developing countries. This trend is driven by factors such as water scarcity, rapid urbanization, and the need for cost-effective irrigation solutions (Kapungwe, 2014). The use of untreated or inadequately treated wastewater for irrigation poses significant health risks due to the presence of pathogens, heavy metals, and organic pollutants. In Ghana, research assessing the quality of water used for vegetable irrigation in the Tamale Metropolis found that a substantial proportion of irrigation water and soil samples contained elevated levels of contaminants, including E. coli, indicating fecal contamination. This practice raises concerns about the safety of consuming vegetables irrigated with such water (Amoah *et at.,* 2021). In developing countries like Nigeria, there has been limited emphasis on installing sewage treatment plants. This contrasts with developed nations, where industrial effluents typically undergo primary and secondary treatments to reduce the concentrations of various toxic elements to safe levels in water and soils. Consequently, subsistence and commercial farming operations, especially in urban areas receiving industrial effluents for irrigation, may produce crops that accumulate these contaminants, posing health risks to consumers (Okafor & Opuene, 2021). The use of untreated wastewater for irrigation in agriculture can introduce harmful substances into the food chain. A study in Northern Nigeria compared heavy metal concentrations in vegetables cultivated using domestic wastewater, industrial effluent, and natural river water, highlighting the potential health risks associated with consuming such produce (Musa & Hamza, 2020). Soil contamination from sewage and industrial effluents adversely affects both soil health and crop productivity. This contamination introduces pollutants such as heavy metals, organic compounds, and pathogens into the soil, leading to reduced fertility and potential health risks for consumers. Environmental contamination due to industrial activities is a major concern in the 21st century. Human activities such as industrial processes, agriculture, fossil fuel combustion, mining, metallurgical operations, and improper waste disposal contribute significantly to soil and water pollution (Smith *et al.,* 2020; WHO, 2018). Industrial operations, including chemical manufacturing, steel production, and metal processing, consume substantial amounts of water, leading to the

generation of various effluents that can significantly contaminate land and water bodies. These activities often result in both direct and indirect soil pollution. For instance, Siyanbola *et al.,* (2011) analyzed industrial effluents in Lagos State, Nigeria, and found that most parameters, including pH, total dissolved solids (TDS), turbidity, biological oxygen demand (BOD), and chemical oxygen demand (COD), exceeded permissible limits, indicating severe pollution of streams.

In Nigeria, the scarcity of quality irrigation water has led farmers to utilize industrial effluents, which often contain heavy metals, for agricultural purposes. This practice can result in the accumulation of metal ions in plants and adversely affect the physicochemical properties of the soil, rendering it unsuitable for agriculture. Farmers in Nigeria often resort to using industrial effluents for irrigation due to high water demand and limited availability of quality water sources. This practice introduces heavy metals into the soil, which can accumulate in crops and negatively impact soil health, making it unsuitable for agricultural use (Hussaini et al., 2021; Lawal & Audu, 2011). These studies highlight the environmental and health risks associated with using industrial effluents for irrigation in Nigeria, emphasizing the need for proper wastewater treatment and sustainable agricultural practices. The environmental impact of mining activities in Nigeria has led to soil contamination, which facilitates the transfer of heavy metals to groundwater, thereby hindering plant growth and posing health risks to nearby populations (Orji *et al.,* 2021). The accumulation of heavy metals in plant tissues can result in the introduction of these metals into the human body through the food chain, potentially causing various health issues. For instance, in Ogoniland, decades of oil spills have severely polluted soils and water sources, leading to the accumulation of toxic substances in crops and posing significant health risks to local communities (The Guardian, 2025). These underscores the significant environmental and health risks associated with heavy metal contamination in Nigeria, highlighting the need for effective remediation strategies and policies to mitigate these hazards. Heavy metals are not easily biodegradable and can accumulate in vital human organs over time, leading to various acute and chronic health issues. For instance, cadmium exposure can result in lung cancer and kidney damage, while mercury exposure may cause neurological disorders and kidney disease. Lead exposure is associated with anemia, and kidney disease, and arsenic exposure can lead to diabetes, skin changes, and cancer (Adal & Wiener, 2023). Chronic exposure to heavy metals, which are not easily biodegradable, can lead to their accumulation in vital human organs, causing various acute and chronic health

issues. For instance, lead exposure has been linked to cardiovascular diseases and central nervous system disorders, while arsenic exposure can result in neuropathic and neurobehavioral issues, as well as reproductive problems (Kumar *et al.,* 2020). This study aims to evaluate how industrial wastewater discharge affects agricultural fields.

MATERIALS AND METHODS

The study was carried out in an industrial area in Nsukka Local Government Area. Nsukka urban is composed of small, well-known towns such as Agu-Echara (Barracks), Onuiyi, Alor-Uno, Edem, Eziani, Ihe, Nru (Ikpa), Umakashi, and Ebulummiri. At an estimated population of 1,205,131, it is situated between latitudes $6^0$49'0"N to $6^0$53'0"N and longitudes $7^0$19'0"E to $7^0$26'0"E. A plateau with isolated outliers of oolithic iron stone-capped hills, the highest of which is 525 meters, is the Nsukka area. On average, the elevation is 350 meters above sea level. The region experiences two main seasons: the rainy season, which starts in March and ends in October, and the dry season, which lasts from October to March. Nsukka receives between 986 and 2,098 mm of rain annually. Between 21°C and 27°C, the air temperature is moderately high. Forest-type vegetation predominates. Nsukka industrial areas houses main industries noteable amongs them are Willson Nigeria Limited, Reynolds Construction Company, Nsukka auto mechanic and spare parts market and building material market just to mention a few. The industry under consideration is among Nigeria's biggest independent producers and distributors of popular and extensively used paint and other household cleaning agents. Without fully understanding the negative impacts, the industry directed its wastewater into a neighboring canal that farmers uses to irrigate their crops. Vegetables and perishables crops are the primary plants cultivated using this industrial waste water, the plants are cultivated all year long.

Sample Collection and Analysis

The study farms were categorized according to how close they were to a paint manufacturing company's wastewater outflow. The following farms were chosen for this study: Farm 1 is located 15 meters from the discharge point, Farm 2 is 30 meters away, Farm 3 is 50 meters away, Farm 4 is 80 meters away, and Farm 5 is 120 meters away. Using Shiprek soil augar cleaned with cotton wool saturated in 70% ethanol, soil samples were gathered at a depth of 0–15 cm from Farms 1–5. Agricultural products, such as corn and

vegetables, were gathered at every sampling distance. The agricultural products included garden eggs (Solanum melongena), potatoes (Solanum tuberosum), okra (Abelmoschus esculentus), guniea corn (Sorghum bicolor), and maize (Zea mays).

We obtained composite soil samples for our study.
Farms 1-5 were air-dried at room temperature for five days, then crushed and sieved through a 2mm sieve to eliminate debris. After sieving, materials were stored in hermetically sealed plastic containers for routine examination. Soil pH was measured with a glass electrode pH meter (MaClean, 1982), and electrical conductivity was calculated with an Elico conductivity meter.

We used the wet dichromate acid oxidation method (Nelson and Sommers, 1982) to determine organic carbon. The total nitrogen was calculated using the Micro Kjedahi method (Bremner, 1982). The available phosphorus was extracted with Bray-P1 solution and quantified using the molybdenum blue method on an auto analyzer adapted by Nelson and Sommers (1982).

Vegetable samples were cleaned with distilled water to remove dust particles. The samples were cut into uniform pieces and air-dried. After air drying, samples were dehydrated for 4-5 days before oven drying at 15°C. Dry vegetable samples were grinded into fine powder and stored in polyethylene bags for acid digestion and analysis. Using a Perkin Elmer A3100 air acetylene flame Atomic Absorption Spectrophometer (AAS), the sample solution was examined for Zn, Cd, Mn, Cr, Fe, Pb, and Cu. Analysis of the reagent blanks was also done, and the atomic absorption spectrophotometer was equipped with D2 background correction devices.

To maintain quality assurance, after being cleaned with distilled water, all of the glass containers used for the experiment were soaked in nitric acid for twenty-four hours. Every reagent used was of analytical quality. In order to eliminate the background metal levels in the chemical and distilled water, blank samples were also examined.

Microsoft Excel was used to examine the acquired data for basic descriptive statistics.

RESULTS AND DISCUSSIONS

The findings of the physico-chemical parameters analyzed in soil samples at various farm locations are shown in Table 1. The pH range between 7.40 and 7.60 of soil samples

indicated an acidic medium, which is of great concern to heavy metal accumulation. The pollution effects of the industrial effluent were also evident with decreased concentrations of soil physico-chemical parameters, including metals, with sampling distance from the discharge point. The increased OC, N, P, and K contents within the vicinity of the discharge point demonstrated the presence of an industrial effluent nutrient source.

Table 1: Physico-Chemical Characteristics of Contaminated Agricultural Soils

Parameter	**Farm 1 5m away**	**Farm 2 10m away**	**Farm 3 30m away**	**Farm 4 50m away**	**Farm 5 80m away**
P^{H}	7.40	7.45	7.50	7.60	7.60
N	0.47	0.44	0.40	0.35	0.25
OC	1.45	1.48	1.50	1.44	1.40
EC	1.37	1.34	1.31	1.30	1.28
P	10.35	10.20	9.80	9.11	8.74
K	4.65	4.51	4.20	4.07	3.72
Na	37.2	34.4	30.7	26.8	22.6
Ca	1002.40	988.6	964.7	943.1	921.3
Mg	45.86	46.2	46.89	48.2	48.91
Zn	3.52	3.35	3.21	3.11	3.02
Cu	0.57	0.54	0.50	0.45	0.45
Fe	168.80	166.70	165.42	165.30	165.15
Pb	3.30	3.27	3.20	3.12	3.04
Mn	4.98	4.91	4.85	4.72	4.70
Cd	0.31	0.30	0.26	0.20	0.15
Cr	1.43	1.38	1.31	1.27	1.25

Table 2 indicates how much accumulated heavy metal is in crops that are watered with industrial wastewater. Vegetables from Farm 1, which is the nearest to the discharge site, have the highest levels of heavy metal accumulation when compared to vegetables from other farms. Moving farther from the discharge point causes the heavy metal value to fall linearly. The effects of the industry are also indicated by the fact that almost all other physico-chemical characteristics of the soils tested for diminish with distance from the discharge site. Additionally, the data demonstrated that while the concentrations of some metals, such as Zn Cu, Fe, and Mn, in agricultural products were high, they decreased marginally distant from the discharge site. According to analysis, these agricultural products were heavily polluted with harmful metals that are bad for the well-being of humans.

All farms' agricultural crops had zinc levels below the WHO standard's maximum permissible limits, with the exception of Farms 1 and 2. A necessary component for bodily metabolism is zinc. However, Zn poses a health risk at greater doses. Diarrhea, vomiting, pancreatic disorders, vascular shock, and dyspeptic nausea can all result from acute zinc exposure. The agricultural products that accumulated the most heavy metals were potatoes, garden eggs, guinea corn, maize, and okro. Agricultural plants have levels of Cd, Pb, and Cr below the detection limit, but the long-term consequences could be harmful to both human health and the environment.

Table 2. Physicochemical Properties of Agricultural Products Watered with Industrial Effluent

	Zn ($MgKg^{-1}$)	**Cu ($MgKg^{-1}$)**	**Fe ($MgKg^{-1}$)**	**Pb ($MgKg^{-1}$)**	**Mn ($MgKg^{-1}$)**	**Cd ($MgKg^{-1}$)**	**Cr ($MgKg^{-1}$)**
Farm 1							
Potatoes	0.85	0.65	11.23	<0.01	1.06	<0.01	<0.01
Guinea corn	0.76	0.13	5.72	<0.01	0.24	<0.01	<0.01
Garden egg	0.87	0.71	7.51	<0.01	0.94	<0.01	<0.01
Maize	0.95	0.73	10.33	<0.01	1.21	<0.01	<0.01
Okro	0.74	0.42	6.12	<0.01	0.31	<0.01	<0.01
Farm 2							
Potatoes	0.72	0.53	10.05	<0.01	1.01	<0.01	<0.01
Guinea corn	0.61	0.09	4.21	<0.01	0.17	<0.01	<0.01
Garden egg	0.78	0.70	6.04	<0.01	0.82	<0.01	<0.01
Maize	0.77	0.28	8.86	<0.01	1.09	<0.01	<0.01

Okro	0.67	0.35	5.04	<0.01	0.21	<0.01	<0.01
Farm 3							
Potatoes	0.65	0.33	9.78	<0.01	1.01	<0.01	<0.01
Guinea corn	0.55	0.11	3.74	<0.01	0.15	<0.01	<0.01
Garden egg	0.60	0.51	5.72	<0.01	0.58	<0.01	<0.01
Maize	0.70	0.21	7.05	<0.01	0.90	<0.01	<0.01
Okro	0.48	0.24	4.78	<0.01	0.21	<0.01	<0.01
Farm 4							
Potatoes	0.54	0.21	7.51	<0.01	0.91	<0.01	<0.01
Guinea corn	0.42	0.11	2.61	<0.01	0.12	<0.01	<0.01
Garden egg	0.33	0.27	3.68	<0.01	0.56	<0.01	<0.01
Maize	0.30	0.13	6.71	<0.01	0.71	<0.01	<0.01
Okro	0.36	0.17	2.51	<0.01	0.16	<0.01	<0.01
Farm 5							
Potatoes	0.42	0.09	5.91	<0.01	0.61	<0.01	<0.01
Guinea corn	0.31	0.07	1.71	<0.01	0.08	<0.01	<0.01
Garden egg	0.22	0.05	2.31	<0.01	0.37	<0.01	<0.01
Maize	0.38	0.12	5.09	<0.01	0.71	<0.01	<0.01
Okro	0.27	0.02	1.28	<0.01	0.06	<0.01	<0.01

The industrial effluent's heavy metal concentrations at the discharge point are shown in Table 3. The effluent had concentrations of Cu, Pb, Zn, Fe, and Cd that were greater than the WHO/ML maximum allowable levels for irrigation water. This is also a sign of pollution, which has an impact on both the environment and human health.

Table 3. Safe Limits of Trace Metals in Agricultural Products

Safe Limits	**Cu**	**Pb**	**Zn**	**Cd**	**Fe**	**Ni**
WHO ($MgKg^{-1}$)	40.00	5.00	0.60	0.0	-	-
WHO recommended max. con of trace elements in waste water for crop production ($MgKg^{-1}$)	0.20	5.00	2.0	0.01	5.00	0.02
WHO/ML of metals in waste water irrigation ($MgKg^{-1}$)	73.00	0.30	100.0	0.10	425.00	67.00
Mean heavy metal content (Mgl^{-1}) of waste water samples taken from affected areas	59.41	22.17	130.21	35.72	1891.71	68.91

Source WHO (2015**)**

CONCLUSION

The findings of this study underscore the significant impact of untreated industrial effluent on soil contamination in the Nsukka Industrial Area, Enugu State. The presence of heavy metals such as cadmium (Cd), lead (Pb), and chromium (Cr) in the soil, although absent in agricultural products, highlights the potential long-term risks of pollution from industrial wastewater discharge. Given that heavy metal concentrations were observed to be higher near the effluent discharge points and lower at locations farther away, it is evident that proximity to industrial activities plays a critical role in determining soil quality.

To mitigate the risks associated with soil contamination, it is strongly recommended that farming activities be conducted at a safe distance from industrial zones. This precautionary measure will help reduce the likelihood of heavy metal accumulation in crops, thereby safeguarding food safety and public health. Additionally, enforcing stricter environmental regulations on industrial wastewater management, promoting the treatment of effluent before discharge, and conducting regular soil quality assessments will be essential in preventing further contamination.

Future studies should focus on assessing the bioavailability of these heavy metals in crops over an extended period and evaluating the effectiveness of soil remediation strategies. This will provide a more comprehensive understanding of the long-term environmental and health implications of industrial effluent discharge on agricultural soil.

Acknowledgement:

We will like to acknowledge the Tertiary Education Trust Fund (TETFUND) for providing the grant for the research.

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