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Original Research Article

Assessment of Heavy Metal Accumulation in *Lactuca sativa* and *Amaranthus caudatus* Irrigated with Effluent from Gusau Water Treatment Plant, Zamfara State, Nigeria

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Abstract: Heavy metal pollution poses significant environmental and health challenges globally, especially in developing countries where untreated industrial effluents are commonly used for irrigation. This study assesses the heavy metal accumulation in Lactuca sativa (lettuce) and Amaranthus caudatus (amaranth) irrigated with effluent from the Gusau Water Treatment Plant, Zamfara State, Nigeria. Effluents and associated agricultural soils were analyzed for physicochemical properties (pH, temperature, electrical conductivity, total dissolved solids) and concentrations of key heavy metals (Cu, Cr, Fe, Pb) using standard methods. Vegetative tissues of lettuce and amaranth were similarly assessed for heavy metal content. Physicochemical analysis revealed variations across sites, with electrical conductivity (EC) at some sites exceeding WHO limits for irrigation, potentially impacting soil and crop health. Heavy metal analysis indicated significant differences in chromium (Cr) concentrations among effluent, soil, and vegetables, while copper (Cu) and lead (Pb) levels remained consistent but low. Iron (Fe) concentrations, though higher, remained within tolerable limits for plant nutrients. Findings suggest that while the effluent supports vegetable cultivation, it poses risks of heavy metal accumulation, with Cr presenting the greatest concern. Regular monitoring and treatment of irrigation effluents are recommended to mitigate risks to human health and the environment.

Keywords: Dissolved Oxygen, Electrical Conductivity, pH, Lead, Temperature.

INTRODUCTION

Heavy metal pollution has become a significant environmental concern globally, particularly in developing countries where industrial effluents are often discharged into the environment without adequate treatment (Khan *et al*., 2013). The use of wastewater for irrigation purposes has been identified as a potential pathway for heavy metal accumulation in plants (Mapanda *et al*.,2005). Lactuca sativa (lettuce) and Amaranthus caudatus (pigweed) are two important leafy vegetables commonly consumed in many parts of the world, including Nigeria (Ogunrinde *et al*., 2017). However, these plants have been reported to accumulate heavy metals when grown in contaminated soil or irrigated with polluted water (Muchuweti *et al*., 2006). Heavy

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metal concentrations in soil are associated with biological and geochemical cycles and are influenced by anthropogenic activities such as agricultural practices, industrial activities and waste disposal methods (Uwah *et al.,* 2009). Heavy metal contamination remains a pressing global concern due to their anthropogenic and natural sources, widespread presence, and detrimental effects on ecosystems. Heavy metals such as cadmium, lead, and arsenic often accumulate in agricultural soils through industrial runoff, improper waste disposal, and excessive use of agrochemicals. These metals exhibit toxic and bio accumulative behavior, posing significant risks to plants, soil microorganisms, and human health when they enter the food chain. Addressing these challenges requires innovative remediation strategies, including bioremediation and soil amendments, to reduce their mobility and toxicity while safeguarding environmental and public health (Panqing et al., 2023; Aransiola *et al*., 2024; Liu *et al*., 2018). The indiscriminate discharge of untreated or inadequately treated wastewater into the environment poses a significant threat to human health and ecological balance. Heavy metals, often present in industrial and municipal effluents, can accumulate in the food chain, potentially causing severe health problems. This study aims to assess the extent of heavy metal accumulation in *Lactuca sativa* (lettuce) and *Amaranthus caudatus* (amaranth), two commonly consumed leafy vegetables, when irrigated with effluent from the Gusau Water Treatment Plant. The investigation will focus on determining the concentrations of various heavy metals in the plant tissues and evaluating the potential health risks associated with their consumption. The vegetable can photosynthesize at high rate even under high temperature. Hence it is grown successfully in hot summer and humid conditions (Mensah *et al*., 2008). It can be uprooted when it is 8 – 10 cm tall (3-4 weeks after sowing) or cut and subsequent cuttings are made at 10 – 15 days interval depending on the vegetative growth. Its flowers mature in 90 - 95 days (ICAR, 2007). Soil is the basic natural source of food production. Plants get most of their nutrients from the soil. In the process of absorbing these nutrients, some are absorbed in large amount depending on their concentrations, soil pH, organic matter content, plant species, age and available form in the soil. Soil contamination by heavy metals and other toxins is generally the result of human activity and this has a negative effect on the productivity, microbiological process of soils, plant growth and development as well as the quality of agricultural products. Although, the content of heavy metals in soils is an important indicator of soil contamination, it is not sufficient to characterize this as environmental hazard as it depends on the forms available, pH, organic matter content, texture, cation exchange capacity (CEC) and moisture condition of the soil. Similarly, translocation of heavy metals from root system to shoot is also another important factor as it differs from only plant to another and the type of element involved (Amusan *et al*., 2005; Karezewska *et al*., 1998; Nirmal *et al*., 2009). Increase in pH, organic content and CEC has shown to reduce the availability of metals. Similarly, existence of carbonate, sulphate and phosphate in a soil creates an increase in a metal precipitation and consequently decreases the metal availability to the plant (Natasa *et al*., 2015). The rapid increase in the population of humans in urban areas of Northern Nigeria has made solid waste handling and disposal a major environmental challenge. Most solid wastes contain paper, food wastes, glasses, synthetic products, batteries, paints, pesticides and metallic containers which are good source of heavy metal accumulation to the soil (Mbong *et al*., 2014).

Heavy metals like Fe, Cu, Zn, and Ni are important for proper functioning of biological systems and their deficiency or excess could lead to a number of disorders (Ward, 1995; Uwah, 2009). Food chain contamination by heavy metals has become a burning issue because of their potential accumulation in bio systems through contaminated water, soil and air. The main sources of heavy metals to vegetable crops are their growth media (soil, air, nutrient solutions) from which these heavy metals are taken up by the roots or foliage (Chen, *et al,* 2005)

Studies on Cd, Cu and Ni levels in vegetables from industrial and residential areas of Lagos City, Nigeria were carried out by (BirninYauri, *et al.* 2011). Which revealed that the levels of Cd, Cu and Ni in different edible vegetables along with the soils on which they were grown were higher in industrial areas than those of the residential areas due to pollution. Also edible portions of five varieties of green vegetables, collected from several areas in Dar Es Salaam, Africa, were analyzed for Pb, Cd, Cr, Zn, Ni and Cu. It was reported that there was a direct positive correlation between Zn and Pb levels in soils with the levels in vegetables (BirninYauri, *et al*. 2011). The Gusau Water Treatment Plant in Zamfara State, Nigeria, discharges effluent into the environment, which is often used by local farmers for irrigation purposes. Therefore, this study aimed to assess the accumulation of heavy metals in Lactuca sativa and Amaranthus caudatus irrigated with effluent from the Gusau Water Treatment Plant.

MATERIALS AND METHODS

Study Area

The study was conducted in behind Gusau water board, around Yardantse area, Gusau Local Government, Zamfara State, Nigeria. It lies at latitudes 11°03'S, 12°47'N and longitudes 3°6'W and 4°27'E. The analysis was conducted at the Laboratory of the Biological Science Department, Federal University Gusau.

Determination of Effluent Physico-chemical Parameters

Surface water physico-chemical parameters viz; temperature, pH, total dissolved solids, electrical conductivity, were determined using methods described by UNEP, (2004); (APHA 2005) and (Panday *et al*., 2005).

Effluent temperature

The surface water temperature was measured *in situ* using portable multifunction pH/EC/Temp/TDSmetre (Model/EZ9908). The metre was allowed to equilibrate after which the value of the surface water temperature was recorded in degree centigrade.

Effluent hydrogen ion concentration (pH)

The surface water pH was measured *in situ* using portable Multifunction pH/EC/Temp/TDSmetre (Model/EZ9908). The metre was allowed to equilibrate before the pH was recorded.

Effluent Total dissolved solids (TDS)

The surface water TDS was measured *in situ* using portable Multifunction pH/EC/Temp/TDS metre(Model/EZ9908). The metre was allowed to equilibrate before the surface water TDS was recorded in part per million (ppm).

Effluent Electrical conductivity (EC)

Electrical conductivity (EC) is a measure of the ability of ions in a solution to carry electric current. This ability depends on the presence of ions, their total concentration and temperature. EC was measured in-situ both in the effluent channels and in the reservoir using multifunction pH/EC/Temp/TDS metre (model/EZ9908). The EC meter was switched on and its probe dipped into the water and allowed to equilibrate. The electrical conductivity was read directly and recorded in µS/cm.

Determination of effluent Heavy Metals Concentration

The method described by (APHA 2005) and (Tanimu, 2015). Was used in determination of some heavy metals (viz; chromium, copper, iron, lead and zinc) from the effluent samples which was filtered through a 0.45 µm membrane filter and preserved in a polyethylene bottle at 4°C. Double acid digestion (HCl 0.1M and Conc. HNO_3) were used to breakdown organic matter and minerals. The aliquot was used for determination of Copper, Cadmium, Iron, Lead and Zinc, using fast sequential atomic absorption spectrometer (VARIAN AA224FS)

Soil samples

The method described by APHA (2005) and (Udo *et al.,* 2009). Soil were spread on trays and placed in the drying room which is kept at room temperature until completely dry and later ground to pass through 1mm pore size of the sieve. All glassware were washed with soap and water, soaked overnight in 5% HNO_3 and after, rinsed with distilled de-ionized water.

Determination of Vegetables heavy metals concentration

Sample vegetables (lettuce and Amaranthus) leaves was cut into small pieces and ground well thoroughly to achieve homogeneity. Digested according to method adapted by (Adefemi. 2007).1.0g were weighed and digested by adding 7 ml of nitric acid to 1g of the weighed sample. 1ml of hydrogen peroxide was then added and the samples were heated in a water bath for 2hrs at 90±5°C. After cooling, the digested samples were adjusted with deionized water to a final volume of 25ml. The final suspended mixture was filtered through an 11µm membrane filter with standard quantitative cellulose filter paper after cooling, the solution was filtered (FAO, 1984) and later analyzed using Atomic Absorption Spectrophotometer (AAS) (APHA, 2005).

Statistical Data Analysis

Data mining and analysis was done using the Statistical Package for Social Sciences (IBM-SPSS) version 23.0. Data were expressed as mean concentrations ± SE, One way analysis of variance (ANOVA), descriptive statistics and Duncan multiple range test (DMRT) post-hoc were used to determine the significant differences between the means of various Physico-chemical parameters. Significant ($p<0.05$) differences accepted at 95%. Data was compared with standard such as WHO, FAO etc.

RESULT AND DISCUSSION

Table 1: Mean±SE Values of Effluent Water Physicochemical Parameters Recorded from February, 2023 to July, 2023

Parameters/ site	SP1	SP2	SP3	SP4	P-value	WHO
pH	6.90^{a}±.085	5.97^{a}±.073	7.89^{a}±.086	6.95^{a}±.035	.879	-
Temp. (^{o}C)	27.62^{a}±.206	27.78^{a}±.234	27.26^{a}±.184	27.76^{a}±.112	.282	-
EC (µS/cm)	257.35^{b}±31.475	875.35^{a}±56.595	705.09^{a}±39.810	618.95^{a}±27.234	.029	250
TDS (ppm)	134.90^{b}±13.518	429.29^{a}±27.681	537.61^{a}±27.467	383.82^{a}±11.993	.015	1000
DO (mg/l)	6.75^{c}±.085	6.18^{c}±.102	6.48^{b}±.083	6.85^{a}±.042	.000	-
BOD_5 (mg/l)	3.13^{a}±.142	2.54^{b}±.052	2.49^{b}±.062	3.20^{a}±.161	.000	5

The findings from Table1: present a comparison of the physicochemical parameters of effluent water recorded from four sampling sites (SP1 to SP4) between February 2023 and July 2023, alongside relevant standards established by the World Health Organization (WHO). Below is an analysis of the results: The pH values ranged from 5.97 (SP2) to 7.89 (SP3), with a mean of 6.90 for SP1, 6.95 for SP4, and no significant differences among sites (P-value = 0.879). These values are generally acceptable for aquatic life, which typically prefers a pH range of 6.5 to 8.5. The temperature across all sites was relatively consistent, ranging from 27.26°C (SP3) to 27.78°C (SP2), with no significant differences (P-value = 0.282). However, the recorded temperatures are within a typical range for water bodies. EC values varied significantly, with SP2 showing the highest mean value of 875.35 µS/cm and SP1 the lowest at 257.35 µS/cm (P-value = 0.029). WHO recommends a maximum EC of 250 µS/cm for drinking water, indicating that SP2 exceeds this standard significantly and may pose risks if used for drinking or irrigation.

TDS values ranged from 134.90 ppm (SP1) to 537.61 ppm (SP3), with significant differences noted among sites (P-value = 0.015). The WHO guideline for TDS is set at a maximum of 1000 ppm; thus, all sites fall within acceptable limits, but SP3 is approaching higher levels that could indicate potential issues if concentrations increase further. DO levels were highest at SP4 (6.85 mg/l) and lowest at SP2 (6.18 mg/l), with significant differences among sites (P-value = 0.000). Levels above 5 mg/l are generally considered sufficient to support aquatic life, indicating that all sites are suitable in this regard. BOD5 values ranged from 2.49 mg/l (SP3) to 3.20 mg/l (SP4), with significant differences observed (P-value = 0.000). The WHO guideline suggests a maximum BOD5 of less than 5 mg/l for effluents; therefore, all sites are within acceptable limits, suggesting low organic pollution levels. While several parameters such as EC and TDS at certain sites exceed recommended limits set by WHO, others like pH, DO, and BOD5 indicate that the effluent is relatively safe concerning organic pollution and oxygen availability for aquatic life. Continuous monitoring is necessary to ensure that the effluent remains within safe limits to protect both human health and environmental quality.

Table 2: Mean ±SE and Range Heavy Metal Concentrations in Effluent, Soil and Vegetables from February, 2023 to July, 2023

Parameters (mg/l)/ site	Effluent	Soil	Lettuce	*Amaranthus*	P-Value
Cu	1.22^{a}±.171	1.27^{a}±.180	1.17^{a}±.150	1.13^{a}±.063	.834
Range	ND-4.52	ND-5.40	ND-3.99	0.02-5.40	
Cr	0.12^{b}±.036	0.31^{c}±.084	0.07^{b}±.034	0.02^{a}±.017	.000
Range	ND-1.090	ND-1.09	ND-1.280	ND-1.53	
Fe	14.99^{a}±6.393	8.66^{ab}±2.926	6.66^{b}±1.792	5.94^{b}±.997	.056
Range	0.016-20.78	0.005-97.13	0.004-59.22	0.007-89.05	
Pb	0.01^{a}±.002	ND	0.01^{a}±.002	0.01^{a}±.001	.647
Range	ND-0.08	ND-0.005	ND-0.08	ND- 0.02	

ND: not detected

The findings presented in Table 2 summarize the mean concentrations of selected heavy metals (Cu, Cr, Fe, Pb) in effluent, soil, and vegetables (lettuce and amaranthus) from February 2023 to July 2023. The mean Cu concentrations were similar across all samples: 1.22 mg/l in effluent, 1.27 mg/l in soil, 1.17 mg/l in lettuce, and 1.13 mg/l in amaranthus. The P-value of 0.834 indicates no significant differences among the sites for Cu concentrations. The mean Cr levels were significantly different across the samples: effluent at 0.12 mg/l, soil at 0.31 mg/l, lettuce at 0.07 mg/l, and amaranthus at 0.02 mg/l. The ranges were ND to 1.090 mg/l for effluent, ND to 1.09 mg/l for soil, ND to 1.280 mg/l for lettuce, and ND to 1.53 mg/l for amaranthus. P-value of 0.000 indicates significant differences in Cr concentrations among the sites. The higher concentration of Cr in soil compared to vegetables suggests potential accumulation in the soil but lower bioavailability in edible parts of the plants. Mean Fe concentrations were as follows: effluent at 14.99 mg/l, soil at 8.66 mg/l, lettuce at 6.66 mg/l, and amaranthus at 5.94 mg/l. Ranges varied widely; effluent from 0.016 to 20.78 mg/l, soil from 0.005 to 97.13 mg/l, lettuce from 0.004 to 59.22 mg/l, and amaranthus from 0.007 to 89.05 mg/l. P-value of 0.056 suggests marginal significance but indicates that there are differences worth noting among the sites.

Pb concentrations were consistently low across all samples with values of 0.01 mg/l in both effluent and vegetables (lettuce and amaranthus), while it was not detected in soil. P-value of 0.647 shows no significant differences among the sites for Pb concentrations.

Overall, the table indicates that while some heavy metals like Cu and Pb are present at low levels across effluents, soils, and vegetables with no significant differences among sites, Cr shows significant variability with higher concentrations in soil compared to edible plants. Fe levels are notably higher but remain within acceptable limits for plant nutrients. Continuous monitoring is essential to assess potential health risks associated with heavy metal accumulation through irrigation practices and consumption of contaminated vegetables.

DISCUSSION

The analysis of physicochemical parameters of effluent water from four sampling sites (SP1 to SP4) between February and July 2023 provides insights into water quality relative to World Health Organization (WHO) standards. Key parameters analyzed include pH, temperature, electrical conductivity (EC), total dissolved solids (TDS), dissolved oxygen (DO), and biochemical oxygen demand (BOD5). The pH values ranged from 5.97 at SP2 to 7.89 at SP3, with no significant differences among sites (P = 0.879). These values, falling within the (WHO, 2018) recommended range of 6.5 to 8.5 for aquatic life, indicate no immediate risk. Temperatures varied minimally between 27.26°C and 27.78°C, showing no significant differences (P = 0.282) and aligning with typical freshwater temperatures, posing no thermal pollution risks. However, the recorded temperatures are typical for freshwater bodies and do not indicate immediate concern regarding thermal pollution (Edokpayi *et al.,* 2024). EC values ranged significantly from 257.35 µS/cm at SP1 to 875.35 µS/cm at SP2 (P = 0.029). SP2 exceeded the WHO limit for drinking water (250 µS/cm), signaling potential issues for drinking or irrigation. TDS values, ranging from 134.90 ppm at SP1 to 537.61 ppm at SP3, also showed significant differences (P = 0.015). While all sites were within the (WHO, 2018) limit of 1000 ppm, SP3's proximity to higher levels warrants monitoring. DO levels, ranging from 6.18 mg/l at SP2 to 6.85 mg/l at SP4 (P = 0.000), exceeded the 5 mg/l threshold generally required for aquatic life, ensuring oxygen availability, indicating that all sites are suitable in this regard (Bi *et al*., 2021). BOD5 values ranged from 2.49 mg/l at SP3 to 3.20 mg/l at SP4 (P = 0.000), staying within the WHO-recommended limit of <5 mg/l, reflecting low organic pollution; therefore, all sites are within acceptable limits, reflecting low organic pollution levels and minimal impact on water quality (Manonmani *et al*., 2020). Heavy metal analysis in effluent, soil, and vegetables showed varying concentrations. Copper (Cu) levels were consistent across samples, with no significant differences (P = 0.834). This result differs from the report of (Kudirat and Funmilayo, 2011). Studies conducted by Adu *et al*., (2012) revealed that levels of Cu, Pb and Zn in spinach that was irrigated with waste water were below the maximum permissible limits of the National Agency for Food and Drug Administration and Control (NAFDA) of Nigeria. Chromium (Cr) concentrations were significantly higher in soil (0.31 mg/l) than in effluent or vegetables (P = 0.000). Iron (Fe) levels were higher in effluent (14.99 mg/l) but remained within safe limits, while lead (Pb) levels were consistently low, indicating minimal contamination risk. (Kudirat and Funmilayo, 2011) Chromium (Cr); Significant differences were noted with higher levels in soil compared to vegetables; mean concentrations were effluent at 0.12 mg/l and soil at 0.31 mg/l (P-value = 0.000). Also found that levels of Cr and Zn in a leafy vegetable sold in 10 markets in Lagos, Nigeria were below the maximum permissible limits according to Nigerian standards. Iron (Fe): Mean Fe concentrations were higher in effluent (14.99 mg/l) compared to vegetables but remained within acceptable limits. Lead (Pb): Consistently low levels across samples suggest minimal contamination risk. The mean concentrations of heavy metals in lettuce from Jimeta dumpsite decreased in the order of; Fe (21.0 mg/kg) > Cu (0.27 mg/kg) > Cr (0.17mg/kg) > Pb (0.15) > Cd (below limit of detection (sakiyo *et al* 2020). Overall, while heavy metals like Cu and Pb are present at low levels across samples without significant differences among sites, Cr shows variability with higher concentrations in soil compared to edible plants.

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