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Determination of Heavy Metals Content and Physico-Chemical Parameters in Soil from Tsamawa, Kaita and Kofar Sauri Irrigation Sites

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Abstract

This research determined heavy metals (Cu, Fe, Cd, Cr, Pb, Ni, Mn, Zn) and physicochemical parameters in soil samples from irrigation sites in Tsamawa (Kano), Kaita, and Kofar Sauri in Katsina. Soil pH ranged from 6.05 in Tsamawa (KISS) to 6.30 in Kofar Sauri (KUSS). Water holding capacity varied between 40.65% in KUSS to 75.53% in Kaita (KSS), while cation exchange capacity ranged from 4.33 Cmol/kg (KUSS) to 6.43 Cmol/kg (KSS). Organic carbon was highest in KSS (2.43), followed by KISS (1.62), and lowest in KUSS (1.39). Organic matter values were 4.20 (KSS), 2.80 (KISS), and 2.40 (KUSS). Soil textures were clay-loam (KSS: 52.2% clay, 32.4% sand, 15.4% silt), sandy-clay-loam (KISS: 62.0% sand, 22.3% clay, 15.7% silt), and sandy-loam (KUSS: 70.3% sand, 14.4% clay, 13.8% silt). Heavy metal concentrations exceeded FAO/WHO limits for Cd, Cr, Mn, Ni, Pb, and Zn. KSS had the highest Cd (1.443 mg/kg), Cu (3.882 mg/kg), and Pb (1.749 mg/kg), while KUSS showed elevated Cr (2.948 mg/kg), Ni (1.193 mg/kg), and Zn (1.701 mg/kg). KISS had the lowest contamination. Fe and Cu remained within safe limits. The findings indicate potential health and environmental risks, requiring remediation and further investigation into pollution sources.

Keywords: Pollution, Heavy metals, Soil, Physico-chemical parameters.

INTRODUCTION

Heavy metals are naturally occurring elements with atomic numbers greater than 20, known for their high density (at least 5 g/cm^3) and toxicity even at low concentration [1, 2]. These elements are present in various amounts in the environment and are integral to many human activities. They are found in essential structures and a variety of artificial mixtures [3, 4] Human activities have significantly altered the biochemical cycles and balance of many heavy metals, leading to their use in products like cars and batteries.

These metals come from both man-made and natural sources and eventually make their way into the environment [5]. Natural sources include volcanic eruptions and the weathering of metal-bearing rocks. Human activities such as the excessive use of chemical fertilizers, wood burning, coal combustion, vehicle emissions, mining, smelting, and incineration have disrupted natural metal cycles, resulting in significant accumulations of heavy metals, particularly in soil [6, 7]. The main heavy metals of concern include lead, cadmium, chromium, zinc, nickel, and manganese due to their toxic effects on human health. High environmental concentrations of these metals have been linked to various cancers and kidney problems [8, 9]. Moreover, heavy metals negatively affect soil microorganisms and plant growth and development [10, 11]. Their persistence and potential for harm have made them a significant environmental concern over recent decades. Besides being non-biodegradable, heavy metals can undergo microbial or chemical transformations [12, 13]. Recent studies by [14] and [15] indicate that environments polluted with heavy metals can activate processes that decrease microbial tolerance to antibiotics due to the co-regulation of antibiotic resistance genes. Heavy metals can contaminate the environment through various pathways. Due to their stability, they can persist in environmental compartments long after initial deposition. Soil and water systems can also become polluted from the weathering of disposed products [16]. Accumulations of heavy metals in plants and soil from natural and artificial sources represent significant pollution problems. Food safety issues and potential health risks make this a serious environmental concern [17]. Some heavy metals, like copper, zinc, manganese, cobalt, and molybdenum, are micronutrients necessary for growth in trace amounts, while others, like cadmium, arsenic, and chromium, are carcinogenic [18]. Mercury and lead are linked to developmental abnormalities in children. Long-term cadmium exposure causes renal, prostate, and ovarian cancers [19]. Excessive levels of heavy metals can cause biochemical effects such as competition for binding sites with essential metabolites, replacement of essential ions, reactions with -SH groups, damage to cell membranes, and reactions with phosphate groups [20].

Irrigation system is known to contribute significantly to heavy metal contents of soils [21, 22]. Majority of crops and vegetables consumed in Kano and Katsina states were produced through irrigation, and mostly the water used by the farmers is waste water from urban or industrial discharges and other waste water channels (including contaminated wells and aquifers) [23, 24]. Therefore, there is need for periodic monitoring of these irrigation sites so as to take appropriate measures to minimize the accumulation of these metals in the soil. Physicochemical parameters analyses will help in ascertaining the soil properties and features that might likely contribute to the accumulation of these metals, while the heavy metals analyses will give us the actual concentration of the metals in the soil whether low, high or within safe limits when compared with world health organization (FAO/WHO) safe limits and standards.

MATERIALS AND METHODS

Description of study areas

Kofar Sauri irrigation area is one of the many irrigation sites located in Katsina urban area, Katsina State. The irrigation area is located at the extreme northern margin of Nigeria, has a total land area of about 3,370 square kilometers and lies between latitudes 11°08'N and 13°22'N and longitude 6°52'E and 9°20'E [19] The Kofar Sauri sampling site has a predominantly ferruginous, tropical red and brown soil, underlain by basement complex rocks. Over large areas, the vegetation does not provide adequate cover for the soils especially at the beginning of the rains; hence the soils are generally susceptible to erosion. The climate is hot and dry for most of the year. Maximum day temperature of about 43 ^{0}C in the months of March, April and May are common and the minimum temperature is about 22 ^{0}C in the month of December and January [20], while the mean annual rainfall is 780mm.

Kofar Sauri irrigation site is located along the major waste channel in a highly populated residential area of Katsina metropolis. The wastewater channel that provides water for irrigation to the farmers was previously a naturally flowing river, called River Ginzo, with a total drainage area of about 6.4 Km^2 and length of 48 Km [21]. The Channel was not contaminated before as it originates from higher areas around Dutsinma but gradually become contaminated due to human activities (domestic, industrial, mechanical, etc.). Substantial crop and vegetable production takes place on the right side of the road, and are being irrigated by the wastewater released from the residential areas [8], some small-scale tanneries, dye-pits, abattoir, car washing, welding, electroplating and painting spots are also located in certain parts of the city, where effluent are being discharged into the waste channel.

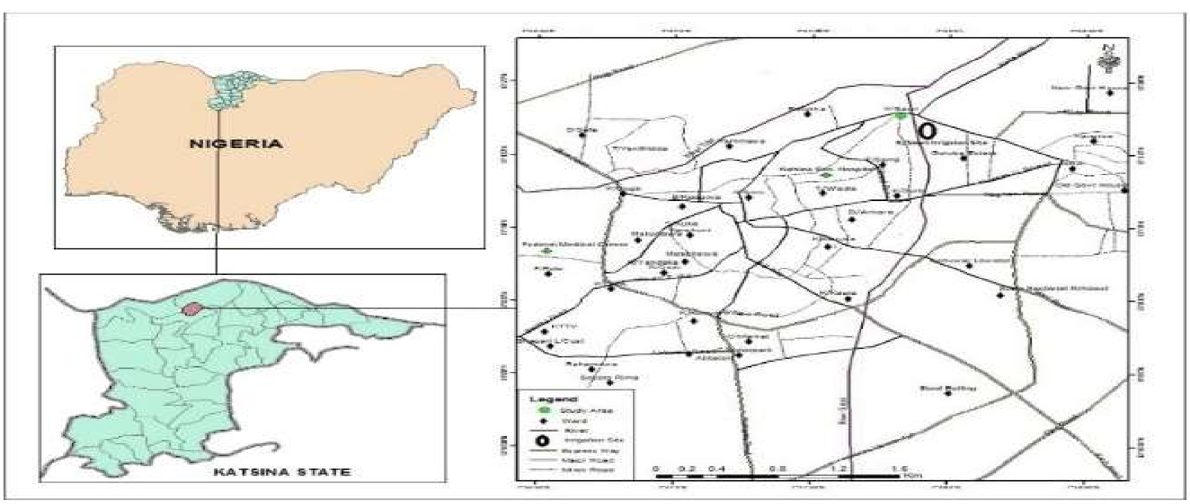

Figure 1. Map showing Kofar Sauri sample area in Katsina city, Nigeria

Kaita is a local government area in Katsina state, it is located in the northern part of the state near the border with Niger. The area is predominantly underlain by Precambrian basement complex rocks, including magnetite, granite gneiss and porphyritic granites. These crystalline formations are occasionally overlain by cretaceous sedimentary rocks of the Gundumi formations (sedimentary layer), which comprises coarse feldspathic grits interbedded with purplish clay and quartz pebbles [22].

The soils are primarily ferruginous tropical red and brown types derived from the weathering of basement rocks and sandy drifts; they are also susceptible.to erosion. The basement complex rocks typically yield low ground water due to their crystalline nature, but areas underlain by Gundumi formations offer higher ground water potential due to porosity and permeability of the sedimentary rocks.

The basement complex rocks, the Gundumi formations containing felspathic grits and quartz pebbles are often rich in naturally occurring heavy metals such as, Pb, Zn, Cu, Cd and As. When these rocks weather and breakdown, they release trace metals into the soil which can lead to elevated metal concentrations particularly in clay-rich soils. Ground water moving through the porous sedimentary layer of Gundumi formation can also mobilise and redistribute metals into the overlying soil [22,23]. Therefore naturally, metals are bound to be present in this irrigation area, and hence, might require remediation

Irrigation in Kaita is carried out using underground water (Tube wells) which the farmers dug in their respective farms. Rice is the major grain grown during rainy season, while wheat and many other vegetables are grown during dry season.

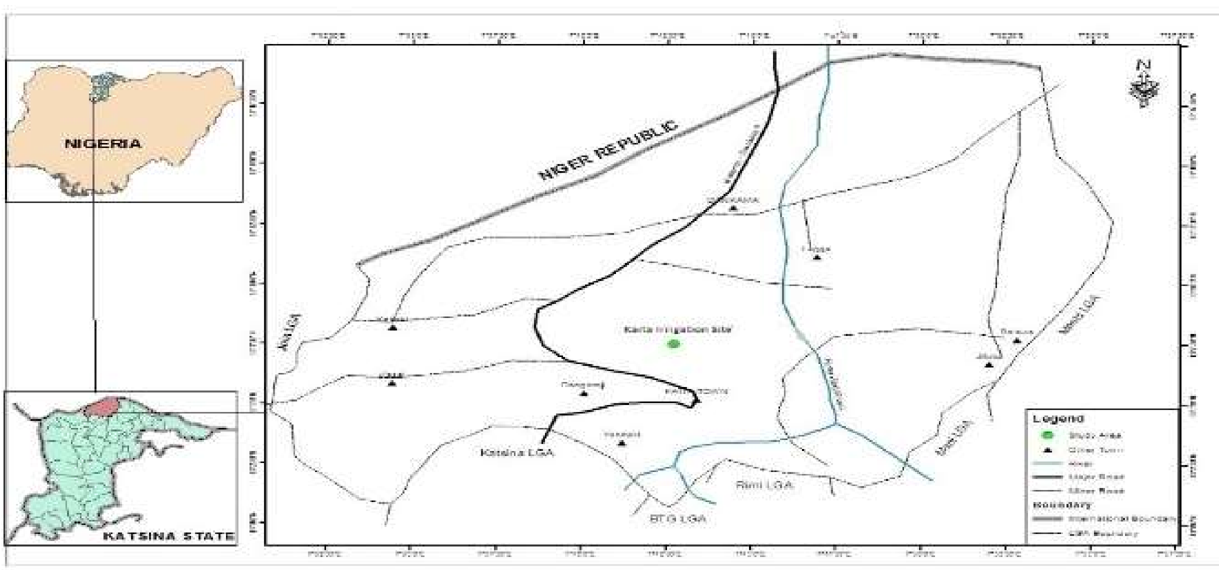

Figure 2. Map showing Kaita sample area in Katsina State, Nigeria

Kano state has more than 18,684 square kilometers cultivable (7,214 sq. mi) of land and is the most extensively irrigated state in the country. Kano has a tradition of irrigated agriculture and is reckoned as the leading hydro agricultural state in Nigeria [24] The sampling site at Tsamawa, Kumbotso local government area lies between latitude 11º50S to 12 ºN and longitude 8º24W to 40E. It falls within the Kano settlement Zone bordering the south and west by Madobi. Northwest by Rimingado and North by Gwale and East by Tarauni local government areas respectively. The regions soil is predominantly tropical ferruginous characterized by sandy textures with low water holding capacities [25], and the area is characterized by ancient crystalline rocks which comprises migmatite gneiss, younger metasediments and granitic intrusions all of which had undergone metamorphic and tectonic activities [26].

Farmers obtain water for irrigation from a river that flows from Kusala at Karaye, to Madobi, to Challawa and then to Tsamawa. The irrigation area is in close proximity to many industries such as, Safari textile limited, Nigeria bottling company (Coca Cola), Fan milk industry, Mamuda agro-allied products, Fata tanning limited, etc. Sugarcane is the major plant grown there and other vegetables such as tomatoes, pepper, cucumber and onions.

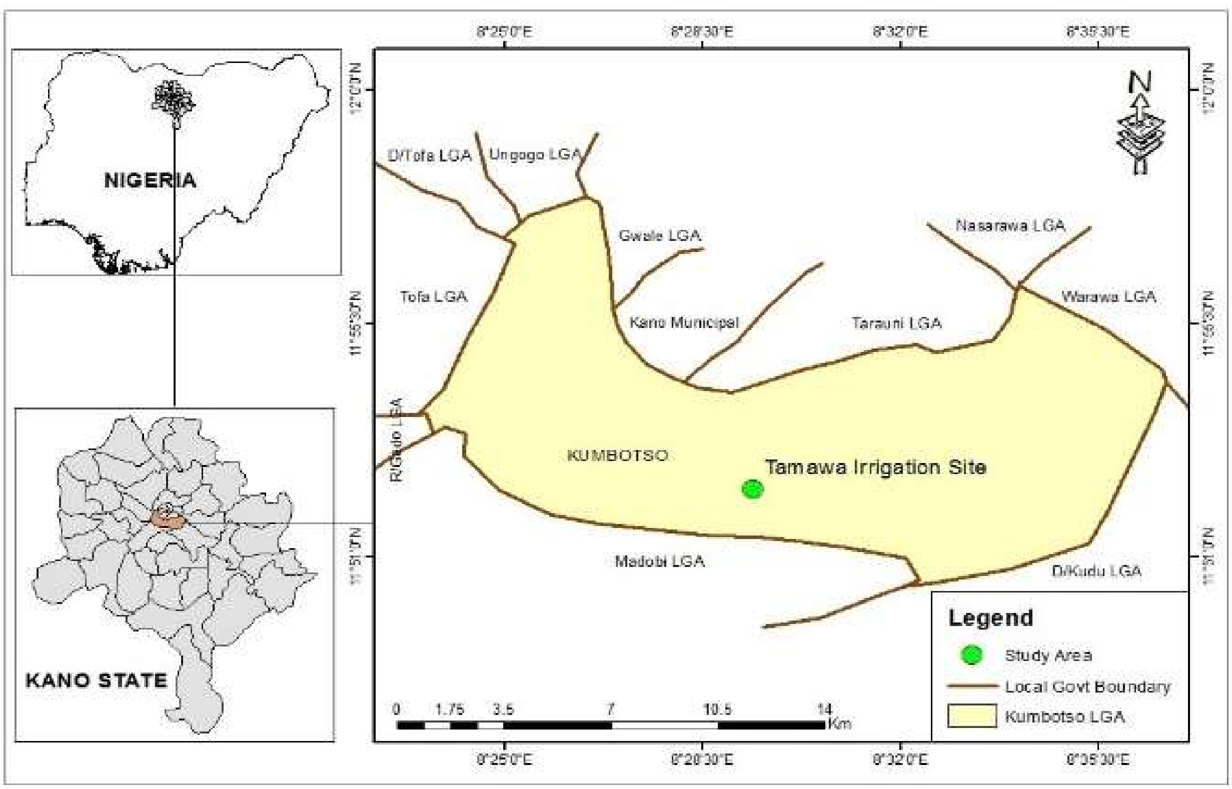

Figure 3. Map showing Tsamawa sample area in Kano State, Nigeria

Sample collection and preparation

The soil samples were collected at random from the irrigation site at Kofar Sauri, Kaita; and Tsamawa at uniform depth of 0-4 cm with the aid of hand trowel. The samples were collected in the month of November, 2023 in replicates which were mixed to form a homogenous sample. They were then air dried for several days at ambient temperature, pulverized and sieved through a 2mm stainless steel mesh [20]. A portion of the soil samples were properly labelled and taken to the soil laboratory at the department of Geography, Umaru Musa Yar'adua University, Katsina for physico-chemical parameters (pH, Cation exchange capacity (CEC), Water holding capacity (WHC), Organic carbon, (OC) Organic matter (OM) and Soil texture) analyses. Some of the prepared samples were measured, digested and taken to Central laboratory at BUK for heavy metals analyses using Atomic Absorption Spectrometry (AAS).

Digestion of soil samples

To determine the heavy metals content in the soil samples wet digestion was carried out. The soil samples (1 g) were placed separately in a beaker with 10 ml mixture of HNO_3 and HCl in the ratio 3:1 (aqua regia). The beaker was heated to 100 °C on a hot plate until almost all the white fumes of nitrogen dioxide has evaporated. The digested soil samples were then cooled and filtered through Whatman No. 4 filter paper. They were then transferred into graduated flasks and deionized water added up to the 50 ml mark [27]. The digests were then transferred to an acid-rinsed sample containers with a label for analysis.

The digests were analysed for their heavy metals (Cd, Cr, Cu, Mn, Ni, Fe, Pb and Zn) content in Central Laboratory, BUK, Kano using Atomic Absorption Spectrometer (AAS) Perkin Elmer, Pinacle 900H model.

Statistical analysis

Data were reported as mean ± standard deviation. Descriptive statistics were used in analyzing the data. Analysis of variance (ANOVA) was used to assess the significant differences between the mean concentrations of the heavy metals and also between the three investigated sites. Tukey's ANOVA was used to assess the significant difference between the adjusted probability values. Correlation matrix was used to determine the association between the levels of the investigated metals. and also, the investigated sites

RESULTS AND DISCUSSION

Physico-chemical parameters analysis. The results obtained for physico-chemical parameters were presented in Table (1).

Table 1. Result of Physicochemical parameters of the soil samples from Kaita (KSS), Tsamawa (KISS) and Kofar Sauri (KUSS) irrigation sites.

Site	pH	WHC (%)	CEC (Cmol/Kg)	OC	OM	Sand (%)	Silt (%)	Clay (%)	Soil texture
KSS	6.10	75.53	6.43	2.43	4.20	32.4	15.4	52.2	Clay- loam
KISS	6.05	49.39	5.72	1.62	2.80	62.0	15.7	22.3	Sandy-clay- loam
KUSS	6.30	40..65	4.33	1.39	2.40	70.8	13.8	14.4	Sandy-loam

In Table (1) above the soil pH values ranged from 6.05 in KISS to 6.30 in KUSS indicating slightly acidic range at all the sampling units which is good for maintaining soil fertility and optimizing essential plant nutrients, as reported by [17] that slightly acidic soils support better bioavailability of essential nutrients, particularly phosphorus, and help limit the toxicity of certain heavy metals.[11] also indicated that acidic conditions may enhance metal mobility, increasing the potential for heavy metal uptake by plants. Other beneficial soil microorganisms also thrive better in slightly acidic conditions improving nutrient cycling. For instance, Penicillium was found to pre-dominates at slightly acidic pH range [28].

The water holding capacity (WHC) and cation exchange capacity (CEC) ranged from 40.65 % (KUSS) to 75.53 % (KSS) and 4.33 Cmol/Kg (KUSS) to 6.43 Cmol/Kg (KSS) respectively. These two parameters greatly help in enhancing soil fertility. They both promote microbial activity by ensuring adequate moisture in the soil, retaining available nutrients and preventing leaching.

KSS has the highest WHC, likely due to its clay-loam texture, which retains more water compared to sandy soils. [8] observed that high WHC enhances nutrient retention and plant growth, especially in semi-arid environments like Katsina and Kano. While KUSS has the lowest, correlating with its sandy-loam texture, which drains quickly and retains less water. [26] identified low WHC in sandy soils of the Kano region which limits their agricultural potential without supplemental irrigation.

CEC was found to be highest in KSS suggesting greater nutrient retention capacity and higher fertility. According to [12], CEC is enhanced by clay and organic matter, both abundant in KSS. While CEC in KUSS was lower which aligns with its sandy texture and lower organic content.[5] emphasized that soils with low CEC are more susceptible to nutrient leaching and metal mobilization, consistent with the sandy profile of KUSS

KSS has the highest value of organic carbon (OC) (2.43), followed by KISS (1.62), while KUSS has the least (1.39); for organic matter (OM) the trend is the same as in OC, the values are 4.20, 2.80 and 2.40 for KSS, KISS and KUSS respectively. [16] recorded total organic carbon in peri-urban farm soils to be within the range of 0.68- 6.32, suggesting possibility of metals retention within the soil, while Organic matter in the same soils ranged from low to high with values varying between 1.18-10.8 which correspond with the findings of this study.

KSS has the highest value of OM which supports better microbial activity, nutrient cycling, and metal-binding capacity. [15] reported that organic matter helps in immobilizing heavy metals, thereby reducing their bioavailability. Whereby, low organic matter in KUSS reduces its capacity to buffer heavy metals and nutrients as reported by [6] that low organic matter soils, allow for higher metal mobility and potential plant uptake, increasing contamination risks. OC is a key component of OM, they increase CEC by providing sites for nutrient exchange [13].

The soil texture for KSS is clay- loam having 52.2 % clay, 32.4 % sand and 15.4 % silt; KISS is sandy- clay- loam having 62.0 % sand, 22.3 % clay and 15.7 % silt; while KUSS is sandy- loam having 70.3 % sand, 14.4 % clay and 13.8 % silt.

KSS, with the highest percentage of clay, is likely to retain both water and metals better than the other two sites. This result agreed with the findings of [2] who highlighted that clay-rich soils can bind metals tightly, making them less bioavailable. KUSS on the other hand, has the highest percentage of sand making it the least effective at retaining both nutrients and metals, increasing leaching and contamination risks downstream. According to [14], sandy soils like those at KUSS can act as conduits for heavy metal mobility due to poor adsorption capacity.

Heavy metals analysis. The results for AAS analysis of the soil samples from the three irrigation sites were presented in Table (2).

Table 2. Mean heavy metal concentrations (mg/kg) in soils from Kofar Sauri (KUSS), Kaita (KSS) and Tsamawa (KISS) irrigation sites.

Heavy metals	KUSS	KSS	KISS	FAO/WHO
Cd	0.118 ± 0.001	1.443 ± 0.008	0.074 ± 0.001	0.01
Cr	2.948 ± 0.012	2.417 ± 0.008	2.060 ± 0.049	1.30
Cu	0.964 ± 0.003	3.882 ± 0.018	0.419 ± 0.002	10.00
Fe	14.56 ± 0.106	12.42 ± 0.024	14.12 ± 0.043	40.00
Mn	6.372 ± 0.020	3.422 ± 0.037	7.188 ± 0.037	0.08
Ni	1.173 ± 0. 008	0.860 ± 0.011	0.789 ± 0.008	0.05
Pb	0.852 ± 0.018	1.749 ± 0.006	0.420 ± 0.017	0.10
Zn	1.701 ± 0.003	1.699 ± 0.005	0.919 ± 0.003	0.60

In table (2) above all the sites exceed FAO/WHO limits for Cd, Cr, Mn, Ni, Pb and Zn indicating potential heavy metal contamination. Kaita (KSS) soil shows the highest contamination for Cd, Cu and Pb with concentration values of 1.443mg/kg, 3.882mg/kg and 1.749mg/kg respectively. Kofar Sauri (KUSS) soil has the highest in Cr, Ni and Zn with concentration values of 2.948mg/kg, 1.193mg/g and 1.701mg/kg respectively. KISS has the lowest concentrations in all the metals.

Cadmium (Cd) level exceeds safe limit (0.01 mg/kg) at all sites with highest concentration value of 1.443 mg/kg recorded in KSS. Cd accumulation in agricultural soils over time is induced by human activities [29], such as excessive application of phosphate fertilizers and pesticides, industrial effluents and waste water from domestic discharges and contaminated underground water. [15] documented similar Cd contamination in tannery-affected regions, suggesting KSS may have anthropogenic sources such as contaminated underground water or agrochemical usage. Cd is highly toxic and associated with renal, bone, and reproductive disorders. [9] reported Cd as causing kidney damage and cancer.

Chromium (Cr) level in all the sites exceed the FAO/WHO limit of 1.30 mg/kg. Highest concentration was recorded in KUSS (2.948 mg/kg), a site receiving effluent from urban and industrial activities (e.g., tanneries, welding, painting). [5] and [11] observed that Cr accumulation often stems from industrial discharge. This report supports the idea that KUSS's urban proximity increases contamination risk.

Manganese (Mg) is a very essential trace metal for plants and animal's growth. Its deficiency produces severe skeletal and reproductive abnormalities in mammals. High concentration of Mn causes hazardous effects on lungs and brains of humans [3]. In this study Mn levels are critically high, especially in KISS with a value of 7.188 mg/kg, KUSS has 6.372 mg/kg, while KSS has the lowest value of 3.422 mg/kg, indicating concentrations higher than the standard limits of FAO/WHO in all the sites. [7] stated that Mn often accumulates from irrigation using low-quality water, a known issue in KISS and KUSS. The result from this study does not correspond with the findings of [30] where values ranging between 0.08 to 0.09 mg/kg were recorded in agricultural soils from Gonglung area, Jere.

Nickel (Ni) is carcinogenic and allergenic and it tends to persist in soils, increasing long-term exposure risks [5]. In this study all sites exceed the threshold limit set by FAOWHO (0.05 mg/kg); highest concentration (1.173mg/kg) was recorded in KUSS. [6] and [14] mentioned that Ni is mobile in sandy soils (like KUSS) which explained the reason behind highest concentration value of Ni in KUSS soil. These findings correspond with the reports by [28] who recorded higher concentrations values (0.37 g/kg – 0.06 g/kg) of Ni in irrigated urban area above USEPA maximum permissible limit which may be attributed to wastewater use. Nickel levels above recommended values can enter into vegetative biomass of vegetables and when consumed by humans can cause lung, liver and kidney damages [10]. It can also cause cancer, respiratory failure, birth defects, allergies, nervous system and heart failure [11].

Lead (Pb) is highly toxic, especially for children, causing cognitive impairment and neurological disorders. Inhalation and ingestion of Pb instigates long term harm in adults and pregnant women with increased risk of high blood pressure and birth deformities respectively [31, 9] emphasized Pb's link to neurodevelopmental issues. Owing to its relevance and usefulness in the metallurgical industry, Highest mean concentration of Pb were recorded in this study which are far above the maximum permissible limit set by FAO/WHO (0.10 mg/kg). KSS has the highest Pb concentration (1.749 mg/kg) which might be as a result of its geological sources, and the lowest concentration was found in KISS (0.852 mg/kg). [15] stated that Pb presence in irrigation systems can reduce microbial diversity affecting soil health.

Copper (Cu) concentrations in all the sites are below the 10 mg/kg limit, hence not posing direct toxicity risks. KSS has the highest Cu (3.882 mg/kg), possibly from natural geological sources (like the Gundumi formation) or use of Cu-based agrochemicals. This finding coincides with the report from [4] which highlighted that Cu from fertilizers and wastewater can accumulate in clay-rich soils like KSS [2] also noted Cu's dual role as both a micronutrient and a pollutant. [8] identified Cu spikes in wastewater-irrigated soils but well below the toxic threshold, similar to KSS findings.

Iron (Fe) levels in all sites are well below the WHO limit of 40mg/kg with KSS having the lowest concentration (12.42 mg/kg), while 14.56 mg/kg and 14.12 mg/kg were recorded in KUSS and KISS respectively. Though not considered toxic at these levels, high Fe can alter soil chemistry and interact with other metals, affecting plant nutrient uptake [12]. [13] emphasized Fe's role in modifying mobility of Pb and Zn under varying redox conditions. Stable Fe levels across the sites reflect background geogenic sources, not pollution.

Zinc (Zn) though essential, is toxic at high concentrations it inhibits photosynthesis and enzyme activity. In this study concentration values of 0.919 mg/kg (KISS) – 1.701 mg/kg (KUSS) were recorded which are all well above the safe limit (0.60 mg/kg), this might be associated to irrigation water sources (Tube wells, urban discharges and industrial discharges) in the sites. This does not correspond with the findings of [20] which obtain Zn values below standard limits in irrigation soil from Katsina urban irrigation site Zn mobility is influenced by pH and organic matter, which explains variation across sites [28].

Table 3 – 4 below represents statistical analyses of data obtained to determine significant difference between heavy metal concentrations and between irrigation sites using Analyses of variance (ANOVA), also between the adjusted probability values (Tukey's ANOVA)).

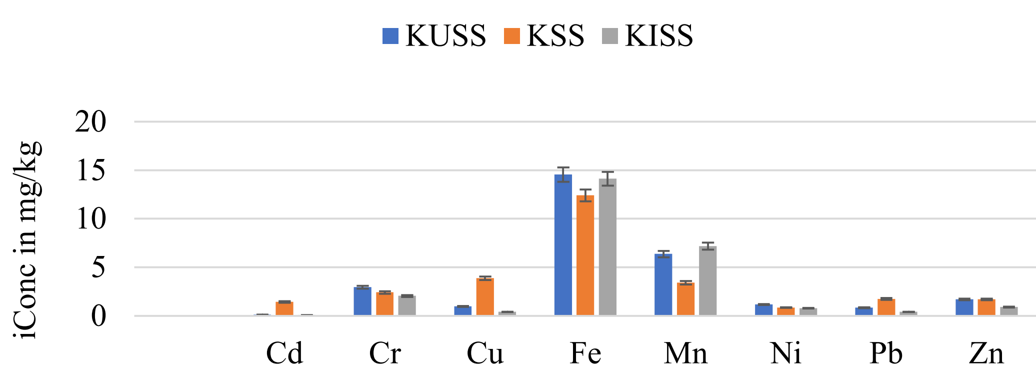

Figure 4. Graphical representation of Heavy metals concentrations in KUSS, KSS and KISS

Table 3. ANOVA for heavy metal concentrations and irrigation sites

Sources	Df	Sum sq	Mean sq	F-value	Pr(>F)
MC	7	1238.5	176.93	6.645	0.000324
IGS	3	57.3	19.10	0.717	0.5527
RESIDUALS	21	559.2	26.63		

From the results obtained in Table (3) it is observed that the probability value for irrigation sites (IGS) is (0.5527) which is greater than the alpha level (0.05), thus, we fail to reject the null hypothesis and conclude that there is no significant difference between the means of the irrigation sites. Despite the data presented in Table (2) showing KSS with the highest concentrations of Cd and Pb, and KUSS with the highest concentrations of Cr, Ni and Zn, the overall variation between sites is statistically insignificant. This Suggests widespread and homogeneous contamination potentially from common practices like: untreated wastewater use [18], over-application of agrochemicals and background geological enrichment, especially in KSS with Gundumi formations [22, 8] found that wastewater irrigation along Katsina's Ginzo channel contributed uniformly to soil pollution, which aligns with this study's results. [20] reported no significant site-based variation in metal concentrations across Katsina's urban farms matching this ANOVA finding.

The probability value for metal concentrations (MC) is (0.000324) which is less than the alpha value, therefore we are to reject the null hypothesis and conclude that there is significant difference between the means of the metal concentrations. This confirms findings from table 2, where Metals like Cd, Cr, Mn, Ni, Pb, and Zn exceeded FAO/WHO safe limits. While Fe and Cu remained within acceptable thresholds. Certain metals are more dominant pollutants and thus pose higher environmental and health risks. This supports a metal-specific remediation strategy as stipulated by [2] and [12] who emphasized the need to differentiate between toxic and essential metals in soil risk assessments.

The residual variance represents unexplained differences in the data. This indicates potential influence from factors not accounted for, such as: sampling time, microbial activity, soil mineralogy, depth variability and seasonal irrigation practices. According to [17], spatial variability in metal uptake and retention in soils is influenced by microclimate, organic matter quality, and soil structure, which may contribute to residual variance.

Table 4. ANOVA for Adjusted Probability Values

MC	Mean Difference	Lower bound	Upper bound	Adjusted p – value
Fe-Cr	18.09375	5.855257	30.332243	0.0014202
Fe-Cu	16.45875	4.220257	28.697243	0.0039364
Mn-Fe	-16.00950	-28.247993	-3.771007	0.0052033
Ni-Fe	-19.55700	-31.795493	-7.318507	0.0005713
Pb-Fe	-19.49475	-31.733243	-7.256257	0.0005937
Zn-Fe	-19.04525	-31.283743	-6.806757	0.0007850

This test was conducted post-ANOVA to determine which specific metal concentrations differ significantly from others. The comparison is made between Fe and other metals (Cr, Cu, Mn, Ni, Pb, Zn). From the results obtained in Table 4 it is observed that all the adjusted probability values are less than 0.05, therefore, this confirmed that there exists a significant difference between the observed metal concentrations (i.e. each pair compared with Fe is significantly different in concentration). The confidence intervals (Lower–Upper) do not include zero, strengthening the reliability of these differences.

Fe (14.56–14.12 mg/kg) is within safe FAO/WHO limits (40 mg/kg) and less variable across sites. Metals like Mn (up to 7.188 mg/kg vs 0.08 FAO/WHO limit), Ni (1.173 vs 0.05), and Pb (1.749 vs 0.10) far exceed FAO/WHO limits, explaining why their concentrations are statistically distinct from Fe [9] and [15]. highlight Pb, Cd, Mn, and Ni as priority pollutants due to their high toxicity and tendency to persist in agricultural systems. [28] shows Zn often accumulates in heavily irrigated soils and can cause toxicity in plants at high levels, consistent with Zn's significant difference from Fe.

Table 5 and 6 represents correlation matrixes for the heavy metals and the irrigation sites to determine possible association between the heavy metals and the irrigation sites.

Table 5. Correlation Matrix for Irrigation Sites

Variable	KUSS	KSS	KISS	FAO
KUSS	1.0000000	0.9361225	0.9944231	0.8677178
KSS	0.9361225	1.0000000	0.9132431	0.9791853
KISS	0.9944231	0.9132431	1.0000000	0.8319281
FAO	0.8677178	0.9791853	0.8319281	

This matrix (table 5) evaluates the degree of linear relationship among the three irrigation sites, KUSS (Kofar Sauri), KSS (Kaita), and KISS (Tsamawa) along with FAO/WHO reference values. Correlation values (r) range from -1 to +1 (+1 = perfect positive correlation, 0 = no correlation and -1 = perfect negative correlation).

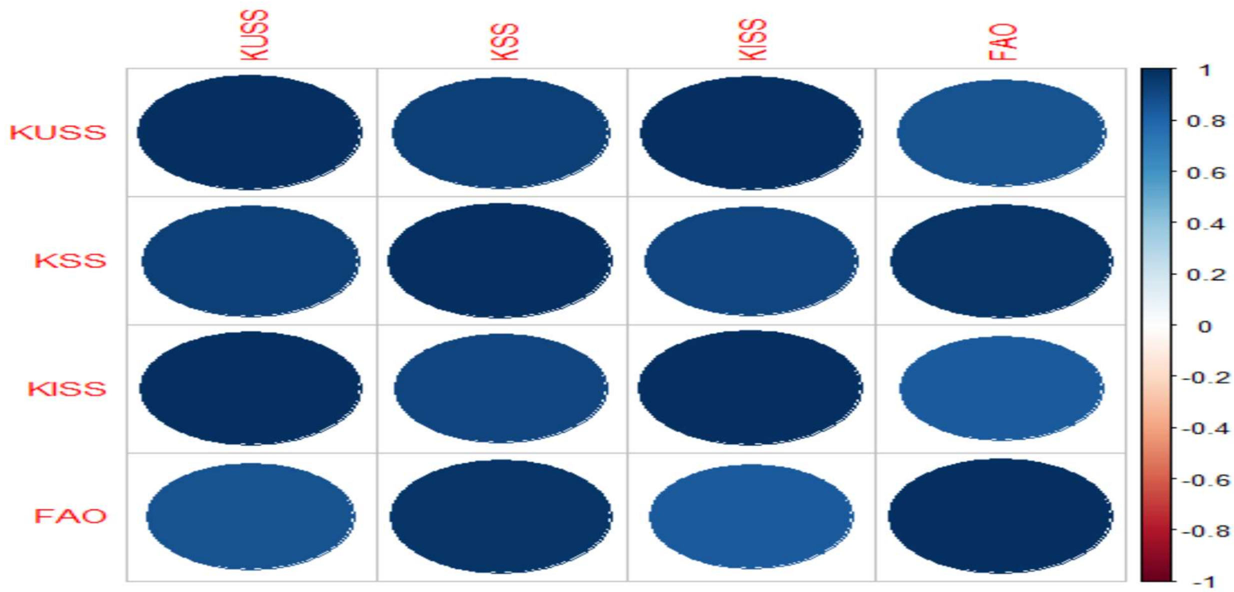

Figure 5. Correlation Plot for Irrigation Sites

From the results obtained in Table 5 and Figure 5 it is observed that there is strong positive correlation between the irrigation sites. The very high correlation (especially between KUSS and KISS) suggests that these sites may be exposed to common pollution sources such as: wastewater irrigation, atmospheric deposition and agrochemical runoff. They may also share soil types or drainage basins, especially in the case of KUSS (urban, waste-channel-fed) and KISS (linked to Kano's industrial river). KSS which is somewhat geologically distinct due to its Gundumi formation, still shows high correlation (0.91–0.94), implying that widespread regional contamination exists.

[20] and [8] reported consistently high heavy metal levels across urban irrigation sites in Katsina, regardless of location confirming this matrix's outcome. [7] emphasized that shared land use patterns (like farming near settlements), and shared water sources (like rivers and drainage basins), lead to correlated pollution patterns across different locations.

[17] found that even geologically distinct areas can show homogenized contamination due to long-term anthropogenic impacts aligning with the high correlation of KSS to others.

Table 6. Correlation Matrix for Heavy Metals

Variable	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn
Cd	1.0000	0.3306	-0.0704	-0.4709	-0.0983	0.2978	0.9437	0.6463
Cr	0.3306	1.0000	-0.7908	-0.8362	0.7099	0.9754	0.6241	0.9189
Cu	-0.0704	-0.7908	1.0000	0.9131	-0.9849	-0.9030	-0.3312	-0.5641
Fe	-0.4709	-0.8362	0.9131	1.0000	-0.8307	-0.9214	-0.6792	-0.7648
Mn	-0.0983	0.7099	-0.9849	-0.8307	1.0000	0.8350	0.1630	0.4302
Ni	0.2978	0.9755	-0.9030	-0.9214	0.8350	1.0000	0.5868	0.8532
Pb	0.9437	0.6241	-0.3312	-0.6792	0.1630	0.5868	1.0000	0.8582
Zn	0.6463	0.9189	-0.5641	-0.7648	0.4302	0.8532	0.8582	1.0000

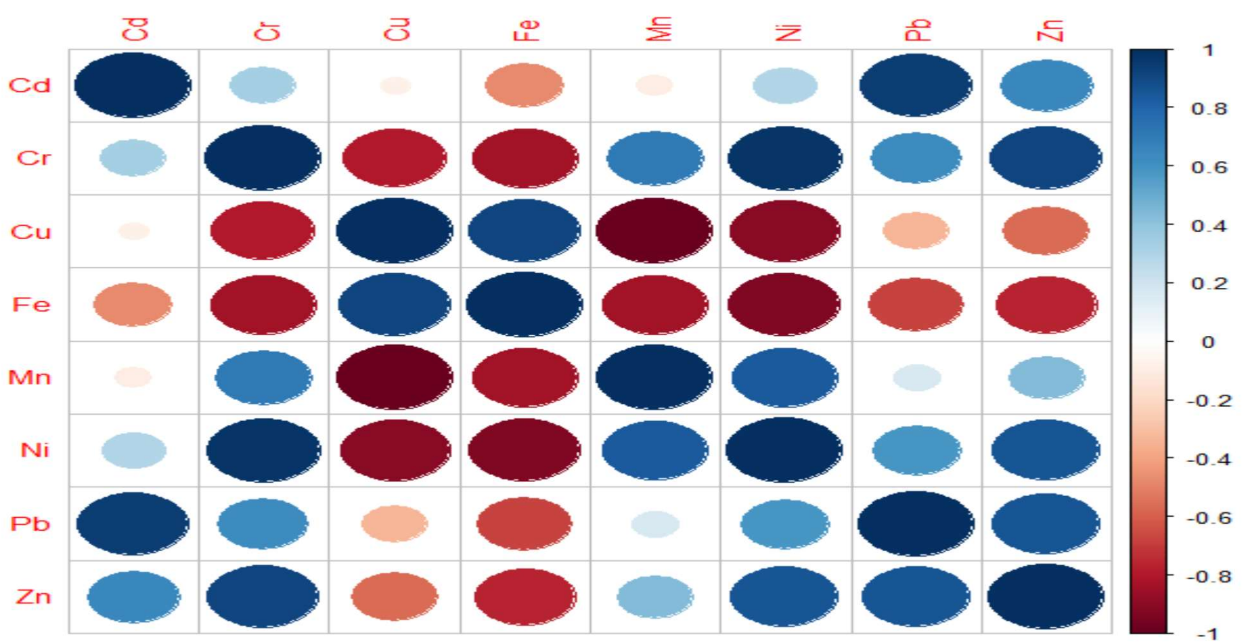

Figure 6. Correlation Plot for Heavy Metals

The matrix presented in Table 6 shows the Pearson correlation coefficients (r) between the concentrations of different heavy metals (Cd, Cr, Cu, Fe, Mn, Ni, Pb, Zn) in the soil samples across all three irrigation sites.

From the results obtained in Table 6 and Figure 6 it is indicated that there are strong positive (r > 0.8) correlation which might be as a result of common or overlapping pollution sources as found between Cd–Pb, Cr-NI, Cr–Zn, Fe–Mn, etc. [15], reported strong co-mobilization of Cd and Pb in soils irrigated with industrial wastewater, confirming the Cd–Pb correlation. In another report by [2], Ni, Cr, and Zn often co-occur in soils exposed to tanneries, electroplating, and sewage discharge, matching the Cr–Ni–Zn pattern here. Moderate positive correlation exists between Cd–Zn and weak positive correlation also between Cd–Ni.

Strong negative correlation (r < -0.8) which might be as a result of biogeochemical interactions, potentially influenced by soil pH, texture, or microbial activity was found between Cr–Cu, Cr–Fe and Fe–Ni. [5] found that metal interactions can be antagonistic or synergistic depending on pH, organic matter, and redox state, explaining Cu–Mn, Cu–Ni negative relationships (r> -0.8). Moderate negative correlation exists between Cd-Fe and weak negative correlation was found between Cd–Cu in the irrigation sites. Mostly heavy metals such as Cd, Pb, Ni, Cr, Zn are interrelated, pointing to combined and systemic contamination. Strong correlations reveal metal clusters, which should be jointly monitored and remediated while, antagonistic relationships may influence metal uptake by crops, necessitating plant-metal interaction studies

CONCLUSION

Kaita (KSS) soil exhibits superior physico-chemical qualities (high WHC, CEC, OC, and a favorable clay-loam texture) ideal for agriculture. However, it also had the highest heavy metal contamination, suggesting input from external pollution sources such as the groundwater used for irrigation, mobilization from Gundumi formations or the soil itself that was formed from weathering of rocks. Tsamawa (KISS) and Kofar Sauri (KUSS) had less favorable soil characteristics, especially KUSS, which has low CEC and OM and a sandy texture, compounding risks of nutrient and metal leaching. These findings suggested that soil quality alone cannot mitigate heavy metal risks; site-specific pollution inputs are crucial in determining contamination levels. Analyses of variance conducted showed significant difference in mean metal concentrations and no significant difference in the irrigation sites. Tukey's ANOVA also confirmed significant variation in metal concentrations. Correlation matrix analyses also showed existence of strong positive correlation between the irrigation sites and variable correlation (strong positive, moderately positive, weak positive, strong negative, moderately negative and weak negative correlations) between the metal concentrations. According to [27], soils contaminated with Pb, Cd, or Cr require urgent intervention due to risks of crop contamination, bioaccumulation, and human toxicity. This suggested potential health and environmental risks, requiring remediation strategies and further investigation into the contamination sources for control such as, industrial effluent regulation and wastewater treatment. Routine monitoring and crop-metal uptake studies are needed to prevent food-chain transfer.

CONFLICT OF INTEREST

Authors declared no conflict of interest.

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ETHICAL STATEMENT

This work required no ethical statement.

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