



Assessment of the Level of Heavy Metals in Irrigation Water, Farm Soil, and Vegetables Grown in Gobbiya Dam, Bogoro Local Government Area Bauchi State, Nigeria.

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Abstract

This study assessed heavy metal concentrations (Pb, Cd, Cu, Cr, As, Fe, Ni) in irrigation water, farm soil, and four vegetable species (kenaf, chili pepper, tomato, and spinach) cultivated around Gobbiya Dam, Bogoro Local Government Area, Bauchi State, Nigeria. Samples were collected from irrigation water, agricultural soil, and different plant parts (roots, stems, leaves, and fruits) and analyzed using Atomic Absorption Spectrophotometry (AAS). Results revealed significant regulatory violations in both soil and water sources, with soil chromium (0.116 mg/kg) exceeding WHO limits (0.10 mg/kg), while irrigation water showed elevated arsenic (0.014 mg/L) and cadmium (0.024 mg/L) above WHO standards (0.01 mg/L and 0.01 mg/L respectively). Soil contamination factors indicated very high contamination for both iron (CF = 10.62) and cadmium (CF = 8.30), while moderate contamination was observed for nickel (CF = 1.66) and chromium (CF = 1.16). Arsenic and lead showed low contamination levels (CF = 1.00 and 0.74 respectively), while copper exhibited the lowest contamination factor (CF = 0.08). Chili pepper demonstrated the highest heavy metal accumulation, particularly cadmium in fruits (0.295 mg/kg), exceeding WHO vegetable safety limits (0.2 mg/kg). Tomato fruits contained arsenic levels (0.055 mg/kg) matching WHO limits, while spinach showed efficient translocation of most metals to leaves. Translocation factor analysis revealed nickel as the most mobile metal across all species (TF range: 1.454 – 4.639), while bioaccumulation factors indicated significant bioaccumulation for arsenic in tomato fruits (BAF = 5.586) and cadmium in chili pepper fruits (BAF = 3.565). Leaves emerged as the primary accumulation site for iron, nickel, and cadmium across all species, while copper showed preferential root sequestration in kenaf and chili pepper. The study concludes that current agricultural practices around Gobbiya Dam pose significant food safety risks due to heavy metal contamination, with chili pepper and tomato fruits presenting the greatest concern for human consumption. Regular monitoring of irrigation water, soil, and vegetable produce for heavy metal contamination should be institutionalized, particularly in dry-season farming areas relying on dam water. Additionally, phytoremediation strategies should be adopted using crops such as kenaf, which demonstrated root retention and lower metal translocation to aerial parts, thus acting as a potential sink for toxic elements

1. Introduction

Human activities such as industrial production, mining, agriculture and transportation, release high amounts of heavy metals into surface and ground water, soils and ultimately to the biosphere. Accumulation of heavy metals in crop plants is of great concern due to the probability of food contamination through the soil root interface. Though heavy metals like, Cd, Pb, Cr, Fe, As, Cu, and Ni are not essential for plant growth, they are readily taken up and accumulated by Plants in toxic forms. Ingestion of vegetables irrigated with waste water and grown in soils contaminated with heavy metals poses a possible risk to human health and wildlife. Heavy metal concentration in the soil solution plays an important role in controlling metal bioavailability to plants. Most of the studies show that the use of waste water contaminated with heavy metals for irrigation over long period of time increases the heavy metal contents of soils above the permissible limit. Ultimately, increasing the heavy metal content in soil and also increases the uptake of heavy metals by plants depending upon the soil type, plant growth stages and plant species [1].

Heavy metals are a group of metallic elements that have high atomic weights and densities at least five times greater than water. These metals include lead (Pb), cadmium (Cd), copper (Cu), arsenic (As), nickel (Ni), chromium (Cr), and iron (Fe), among others. Due to their widespread industrial use, natural occurrence, and anthropogenic activities, heavy metals have become significant environmental contaminants. Their presence in soil, water, and biota poses serious ecological and health risks, especially when they accumulate to toxic levels [2]. The characteristics of heavy metals that make them particularly concerning in environmental contexts are their non-biodegradable nature and their tendency to bioaccumulate and biomagnified within ecosystems. Unlike organic pollutants, heavy metals tend to remain in the environment for extended periods, often undergoing complex chemical transformations that influence their mobility and toxicity. Their persistence is compounded by their ability to bind with organic and inorganic matter, which can either immobilize them temporarily or facilitate their long-range transport [3].

Heavy metals such as lead, cadmium, mercury, arsenic, copper, and iron are toxic to humans and can cause various health problems, including cancer, neurological disorders, and kidney damage [4]. The assessment of heavy metal levels in irrigation water, soil, and vegetables is essential to ensure food safety and protect public health. Environmental pollution has been one of the most serious global challenges facing communities living in an industrial area, particularly in developing countries like Nigeria. Environmental pollution can as a result of unfavorable production of man's activities such as mining, combustion, applications of fertilizers and pesticides [5, 6]. Chemical substances from the activities such as heavy metals are one of the factors which contribute to environmental pollutions and it is believed that it can disrupt the living ecosystem [7].

The uncontrolled irrigation of crops with sewage water leads to the accumulation of some potentially toxic metals in agricultural soil and have very adverse effects on the growth of the plants [8]. It is now a common practice in many parts of Nigeria to use municipal sewage water that contain both industrial effluents and domestic liquid waste for irrigation purpose [9, 10]. This research aimed to investigate the contaminations of heavy metals in Gobbiya dam water and soil used for irrigation farming, as well as their potential transfer to vegetables. The specific objectives are:

1. To assess the levels of heavy metals (lead, cadmium, chromium, copper, arsenic, nickel, and iron) in irrigation water, farm soil, and vegetables.
2. To identify the vegetable species that accumulates high levels of heavy metals (tomato, kenaf, spinach, and chili pepper).
3. To identify part of the vegetables that accumulates high level of the heavy metals.
4. To determine bioaccumulation factor (BAF), and translocation factor (TF) of the heavy metals within the vegetables.

2. Methodology

2.1. Description of the Study area

The study was conducted in Gobbiya dam in Bogoro local government area of Bauchi state, Nigeria. Bogoro is located at an elevation of 584 meters above sea level; it has an area of 894 km² and a population of 84,213 as at the 2006 census.

2.2. Water sample collection and preservation

Water sample from the study area was collected into 120ml sterile bottle. The water was acidified with 2ml of analytical grade nitric acid for heavy metal analysis in order to preserve metals and avoid precipitation as performed [11]. The water sample was chemically analyzed using standard methods [12].

2.3. Soil sample collection and preservation

The soil sample was collected from the study area; approximately 0.5 kg of soil was collected (0 – 20cm depth) with the help of stainless-steel spoon and made into a composite sample. The soil sample was then placed into a nitric acid treated polythene bag to prevent metals from adhering to the container and then transported to the laboratory where they were air-dried for about 3days then oven-dried to constant weight at 105⁰C, disaggregated in a ceramic pestle and mortar, ground to powder and sieved [13].

2.4. Vegetable sample collection and preservation

Vegetables: *Spinacia oleracea* (spinach), *Hibiscus cannabinus* (kenaf), *Solanum lycopersicum* (tomato), and *Capsicum annum* (chili pepper), were harvested from the study area, packaged in polyethylene bags and labeled. These were immediately transported to the laboratory. All samples collected were carefully washed with distilled water to remove soil and other impurities, and then dried in an oven at 80°C for 24 hours. After drying, the samples were pulverized using mortar and pestle into fine powder, sieved and kept in air tight containers [14].

2.5. Treatment of water sample for heavy metal analysis

75ml of the water sample was measured into a digestion flask; and 25ml of concentrated HNO₃ acid was added to the flask and heated on a hot plate for 1 hour. The digested sample was allowed to cooled and thereafter quantitatively transferred to 100ml volumetric flask and the volume adjusted to 100ml with deionized water [15]. The sample was then taken for atomic absorption spectroscopy (AAS).

2.6 Treatment of soil sample for heavy metal analysis

1g of prepared soil sample was placed into 150ml digestion flask, a mixture of Nitric acid (HNO₃), and Perchloric acid (HClO₄) is added in the ratio 2:1. The mixture was then placed on a hot plate and heated for three hours at 80°C. The digests was then filtered into 100ml standard flask and made to mark with distilled water. The sample was then taken for atomic absorption spectroscopy (AAS).

2.7. Treatment of vegetable samples for heavy metal analysis

1g of each sample was taken into kjeldal digestion flask, mixed with 10cm³ of aqua-regia (concentrated sulphuric acid, concentrated perchloric acid and concentrated nitric acid in the ratio 1:2:2 respectively) and left to stand overnight. There after the flask was heated at 70°C for 40 minutes after which the temperature was raised to 120°C. The heating continued until clear solutions were obtained which produced white fumes. The digest were diluted with 20cm³ of distilled water, boiled for 15minutes, allowed to cool and then transferred into 100cm³ volumetric flasks and diluted to the mark with distilled water. The sample solutions were then filtered using a filter paper in a

screw capped polyethylene bottle and finally, the samples were taken for atomic absorption spectroscopy (AAS) [16].

2.8. Data analysis

All experiments were conducted in replicate measurements and presented as mean $\pm$ SD. Data obtained were analyzed using Microsoft Excel 2013. The mean values were subjected to one-way analysis of variance (ANOVA) at 95% confidence level using Graph Pad Prism Software (Graph Pad Inc., San Diego, CA, USA) (6) at $p < 0.05$ followed by Turkeys Multiple Comparison of means.

3. Results

Table 1: Heavy Metal Concentrations in Kenaf Plant, Soil and Water

Samples	As	Fe	Cd	Cu	Cr	Pb	Ni
Kenaf stem	0.004 $\pm$ 0.005 ^a	0.169 $\pm$ 0.095 ^b	0.029 $\pm$ 0.005	0.037 $\pm$ 0.027 ^b	0.063 $\pm$ 0.022 ^b	0.018 $\pm$ 0.003 ^b	0.017 $\pm$ 0.016 ^b
Kenaf Root	0.027 $\pm$ 0.020 ^a	0.249 $\pm$ 0.143 ^b	0.032 $\pm$ 0.000	0.408 $\pm$ 0.095 ^b	0.066 $\pm$ 0.011 ^b	0.036 $\pm$ 0.003 ^b	0.044 $\pm$ 0.033 ^b
Kenaf leaves	0.018 $\pm$ 0.015 ^a	0.536 $\pm$ 0.076 ^b	0.064 $\pm$ 0.004	B.D.L ^b	0.082 $\pm$ 0.017 ^b	0.051 $\pm$ 0.006 ^b	0.181 $\pm$ 0.105 ^b
WHO limits (veg.)	0.05 ^a	20 ^a	0.2 ^a	73 ^a	1.3 ^a	2 ^a	10 ^a
Soil	0.010 $\pm$ 0.009 ^d	10.616 $\pm$ 0.003 ^d	0.083 $\pm$ 0.003 ^d	0.105 $\pm$ 0.014 ^d	0.116 $\pm$ 0.009 ^c	0.037 $\pm$ 0.005 ^c	0.331 $\pm$ 0.016 ^d
WHO limits (soil)	20 ^c	50 ^c	0.80 ^c	36 ^c	0.10 ^c	0.10 ^c	35 ^c
Water	0.014 $\pm$ 0.009 ^e	0.306 $\pm$ 0.036 ^f	0.024 $\pm$ 0.001 ^e	0.016 $\pm$ 0.023 ^f	0.029 $\pm$ 0.003 ^e	0.013 $\pm$ 0.002 ^e	0.088 $\pm$ 0.042 ^f
WHO limits (water)	0.01 ^e	1.0 ^e	0.01 ^e	1.3 ^e	0.10 ^e	0.05 ^e	0.2 ^e

Units: mg/kg for plant parts and soil; mg/L for water

B.D.L = Below Detection Limit

Values represent mean $\pm$ standard deviation ($n=3$)

Values in the same column with ^{b,d,f} superscripts differ significantly ($p < 0.05$) than WHO permissible limits for Vegetables, soil and water respectively.

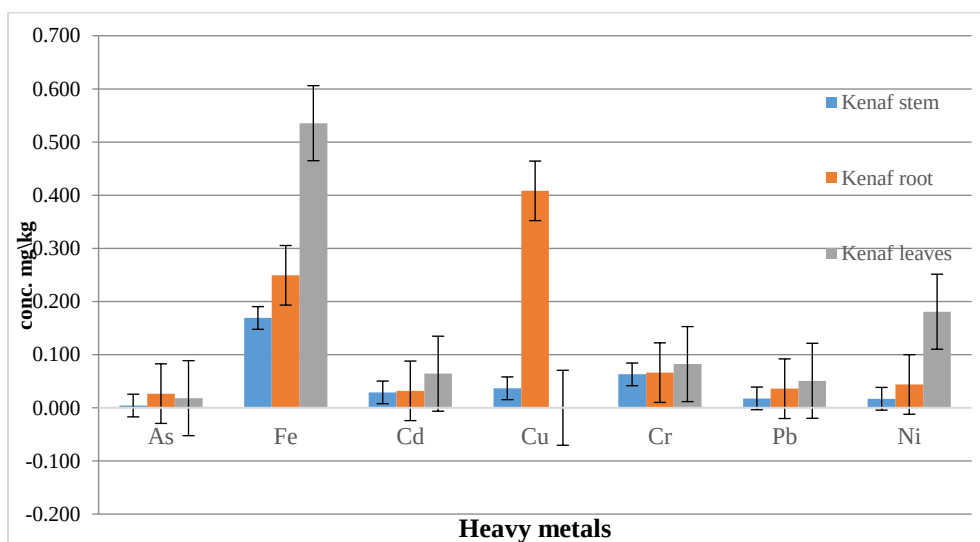


Fig.1 Heavy Metal Concentrations in Kenaf's Leaves, Root & Stem

WHO Permissible limits for vegetables:

As 0.5, Fe 20, Cd 0.2, Cu 73, Cr 1.3, Pb 2, Ni 10

Table 2: Heavy Metal Concentrations in Chili Pepper Plant, Soil and Water

Samples	As	Fe	Cd	Cu	Cr	Pb	Ni
Chili pepper stem	0.049± 0.001 ^a	0.306± 0.078 ^b	0.042 ± 0.002 ^a	0.343± 0.143 ^b	0.078± 0.004 ^b	0.032± 0.005 ^b	0.047± 0.034 ^b
Chili pepper root	0.039± 0.021 ^a	0.976± 0.098 ^b	0.049 ± 0.005 ^a	0.455± 0.025 ^b	0.068± 0.007 ^b	0.037± 0.001 ^b	0.055± 0.013 ^b
Chilipepper leaves	0.027± 0.007 ^a	0.983± 0.108 ^b	0.058 ± 0.005 ^a	0.145± 0.123 ^b	0.088± 0.006 ^b	0.052± 0.003 ^b	0.255± 0.095 ^b
Chili pepper fruits	0.032± 0.004 ^a	1.358± 0.114 ^b	0.295 ± 0.307 ^a	0.347± 0.036 ^b	0.078± 0.011 ^b	0.048± 0.007 ^b	0.217± 0.083 ^b
WHO limits (veg.)	0.05 ^a	20 ^a	0.2 ^a	73 ^a	1.3 ^a	2 ^a	10 ^a
Soil	0.010± 0.009 ^d	10.616± 0.003 ^d	0.083 ± 0.003 ^d	0.105± 0.014 ^d	0.116± 0.009 ^c	0.037± 0.005 ^c	0.331± 0.016 ^d
WHO limits (soil)	20 ^c	50 ^c	0.80 ^c	36 ^c	0.10 ^c	0.10 ^c	35 ^c
Water	0.014± 0.009 ^e	0.306± 0.036 ^f	0.024 ± 0.001 ^e	0.016 ± 0.023 ^f	0.029± 0.003 ^e	0.013± 0.002 ^e	0.088± 0.042 ^f
WHO limits (water)	0.01 ^e	1.0 ^e	0.01 ^e	1.3 ^e	0.10 ^e	0.05 ^e	0.2 ^e

Units: mg/kg for plant parts and soil; mg/L for water

Values represent mean ± standard deviation (n=3)

Values in the same column with ^{b,d,f} superscript differ significantly ($p<0.05$) than WHO permissible limits for Vegetables, soil, and water respectively.

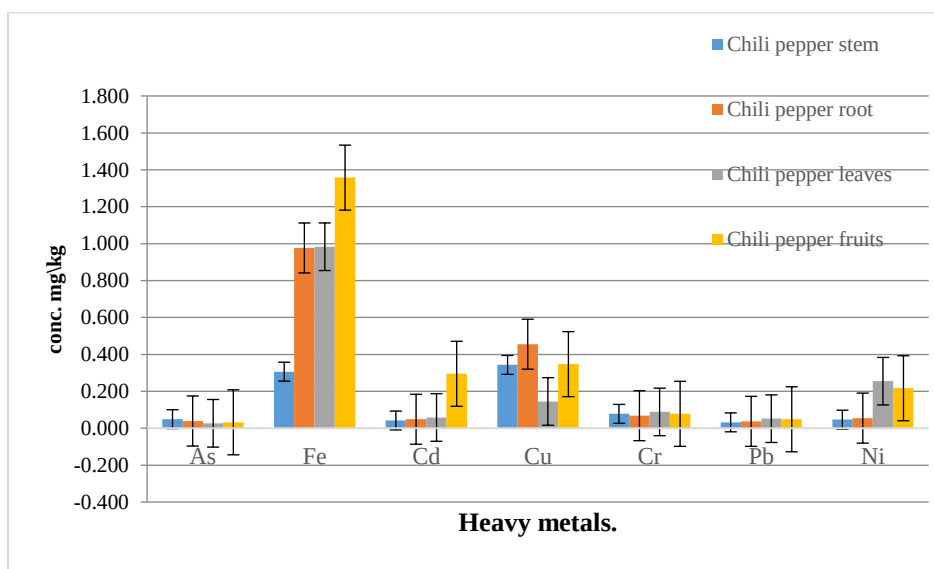


Fig.2 Heavy Metal Concentrations in Chili Pepper's Leaves, Root, Stem & Fruits

WHO Permissible limits for vegetables:

As 0.5, Fe 20, Cd 0.2, Cu 73, Cr 1.3, Pb 2, Ni 10

Table 3: Concentration of Heavy Metals in Tomato Stem, Root, Leaves, Soil and Water

Samples	As	Fe	Cd	Cu	Cr	Pb	Ni
Tomato stem	0.021± 0.008 ^a	0.295± 0.140 ^b	0.055 ± 0.005 ^b	0.079± 0.079 ^b	0.052± 0.023 ^b	0.043± 0.005 ^b	0.096± 0.008 ^b
Tomato root	0.030± 0.002 ^a	0.566± 0.062 ^b	0.058 ± 0.003 ^b	0.142± 0.130 ^b	0.047± 0.006 ^b	0.041± 0.004 ^b	0.178± 0.050 ^b
Tomato leaves	0.015± 0.009 ^a	1.292± 0.044 ^b	0.068 ± 0.004 ^b	0.167± 0.094 ^b	0.068± 0.006 ^b	0.056± 0.002 ^b	0.313± 0.044 ^b

Tomato fruits	0.055± 0.001 ^a	0.563± 0.050 ^b	0.084 ± 0.004 ^b	0.064± 0.053 ^b	0.101± 0.010 ^b	0.043± 0.006 ^b	0.267± 0.051 ^b
WHO limits (veg.)	0.05 ^a	20 ^a	0.2 ^a	73 ^a	1.3 ^a	2 ^a	10 ^a
Soil	0.010± 0.009 ^d	10.616± 0.003 ^d	0.083± 0.003 ^d	0.105± 0.014 ^d	0.116± 0.009 ^c	0.037± 0.005 ^c	0.331± 0.016 ^d
WHO limits (soil)	20 ^c	50 ^c	0.80 ^c	36 ^c	0.10 ^c	0.10 ^c	35 ^c
Water	0.014± 0.009 ^e	0.306± 0.036 ^f	0.024 ± 0.001 ^e	0.016± 0.023 ^f	0.029 ± 0.003 ^e	0.013± 0.002 ^e	0.088± 0.042 ^f
WHO limits (water)	0.01 ^e	1.0 ^e	0.01 ^e	1.3 ^e	0.10 ^e	0.05 ^e	0.2 ^e

Units: mg/kg for plant parts and soil; mg/L for water

Values represent mean ± standard deviation (n=3)

Values in the same column with ^{b,d,f} superscript differ significantly ($p<0.05$) than WHO permissible limits for Vegetables, soil, and water respectively.

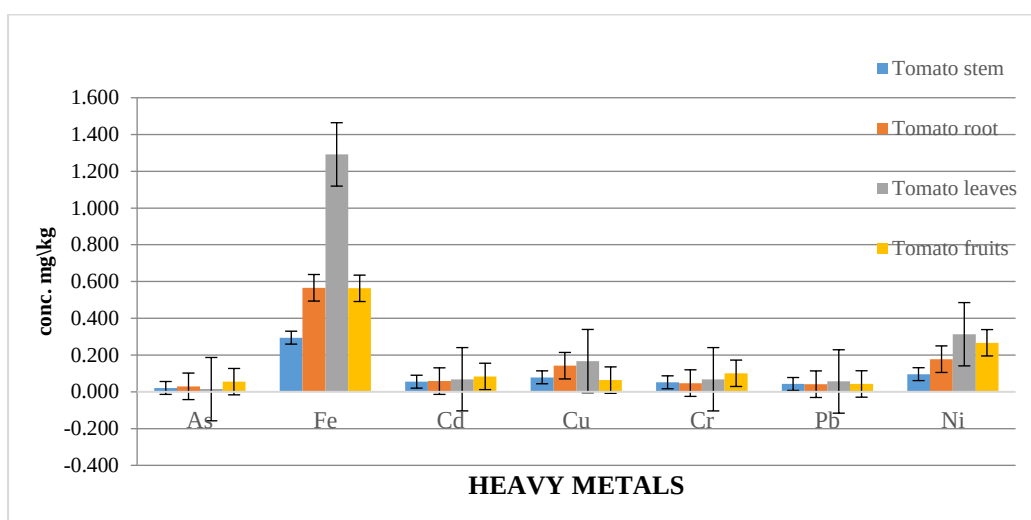


Fig.3 Heavy Metal Concentrations in Tomato's Leaves, Root, Stem & Fruits.

WHO Permissible limits for vegetables:

As 0.5, Fe 20, Cd 0.2, Cu 73, Cr 1.3, Pb 2, Ni 10

Table 4: Heavy Metal Concentrations in Spinach Plant, Soil and Water

Samples	As	Fe	Cd	Cu	Cr	Pb	Ni
Spinach stem	0.023± 0.018 ^a	0.495± 0.028 ^b	0.062 ± 0.005 ^b	B.D.L ^b	0.081± 0.005 ^b	0.062 ± 0.005 ^b	0.119± 0.025 ^b
Spinach root	0.007 ± 0.010 ^a	1.024± 0.102 ^b	0.067 ± 0.001 ^b	0.041± 0.058 ^b	0.076± 0.008 ^b	0.058± 0.004 ^b	0.205± 0.052 ^b
Spinach leaves	0.025± 0.011 ^a	1.345± 0.104 ^b	0.075 ± 0.002 ^b	0.242 ± 0.028 ^b	0.079 ± 0.008 ^b	0.052± 0.004 ^b	0.298± 0.020 ^b
WHO limits (veg.)	0.05 ^a	20 ^a	0.2 ^a	73 ^a	1.3 ^a	2 ^a	10 ^a
Soil	0.010± 0.009 ^d	10.616± 0.003 ^d	0.083 ± 0.003 ^d	0.105± 0.014 ^d	0.116± 0.009 ^c	0.037± 0.005 ^c	0.331± 0.016 ^d
WHO limits (soil)	20 ^c	50 ^c	0.80 ^c	36 ^c	0.10 ^c	0.10 ^c	35 ^c
Water	0.014± 0.009 ^e	0.306± 0.036 ^f	0.024± 0.001 ^e	0.016± 0.023 ^f	0.029± 0.003 ^e	0.013± 0.002 ^e	0.088± 0.042 ^f
WHO limits (water)	0.01 ^e	1.0 ^e	0.01 ^e	1.3 ^e	0.10 ^e	0.05 ^e	0.2 ^e

Units: mg/kg for plant parts and soil; mg/L for water

B.D.L = Below Detection Limit

Values represent mean ± standard deviation (n=3)

Values in the same column with ^{b,d,f} superscript differ significantly ($p<0.05$) than WHO permissible limits for Vegetables, soil, and water respectively.

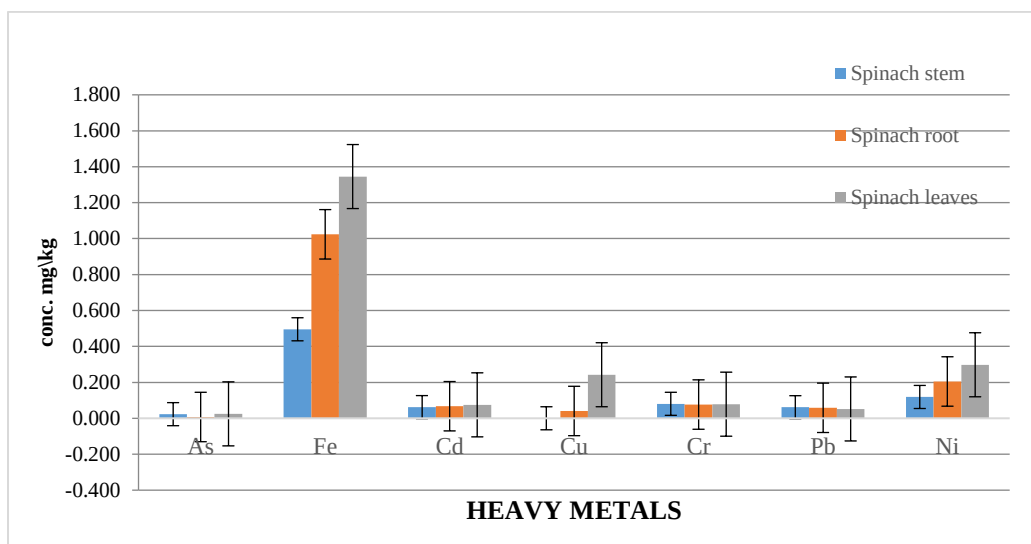


Fig.4 Heavy Metal Concentrations in Spinach Leaves, Root & Stem.

WHO Permissible limits for vegetables:

As 0.5, Fe 20, Cd 0.2, Cu 73, Cr 1.3, Pb 2, Ni 10

Table 5: Bioaccumulation Factors (BAF) for Kenaf, Chili Pepper, Tomato and Spinach Different Parts

Plant's Parts	As	Fe	Cd	Cu	Cr	Pb	Ni
Kenaf stem	0.424	0.016	0.351	0.350	0.545	0.484	0.051
Kenaf root	2.687	0.023	0.386	3.902	0.572	0.981	0.133
Kenaf leaves	1.828	0.050	0.775	0.000	0.712	1.388	0.547
Chili pepper stem	4.960	0.029	0.507	3.280	0.674	0.863	0.141
Chili pepper root	3.949	0.092	0.589	4.352	0.586	1.016	0.166
Chili pepper leaves	2.697	0.093	0.704	1.386	0.763	1.410	0.770
Chili pepper fruits	3.222	0.128	3.565	3.318	0.674	1.320	0.655
Tomato stem	2.131	0.028	0.669	0.754	0.448	1.169	0.291
Tomato root	3.030	0.053	0.704	1.359	0.410	1.131	0.537
Tomato leaves	1.475	0.122	0.827	1.598	0.591	1.541	0.947
Tomato fruits	5.586	0.053	1.015	0.609	0.874	1.169	0.807
Spinach stem	2.313	0.047	0.751	0.000	0.698	1.683	0.359
Spinach root	0.727	0.096	0.811	0.389	0.661	1.596	0.619
Spinach leaves	2.475	0.127	0.903	2.317	0.681	1.415	0.901
<i>Minimum BAF</i>	<i>0.424</i>	<i>0.016</i>	<i>0.351</i>	<i>0.000</i>	<i>0.410</i>	<i>0.484</i>	<i>0.051</i>
<i>Maximum BAF</i>	<i>5.586</i>	<i>0.128</i>	<i>3.565</i>	<i>4.352</i>	<i>0.874</i>	<i>1.683</i>	<i>0.947</i>

BAF > 1 indicates bioaccumulation

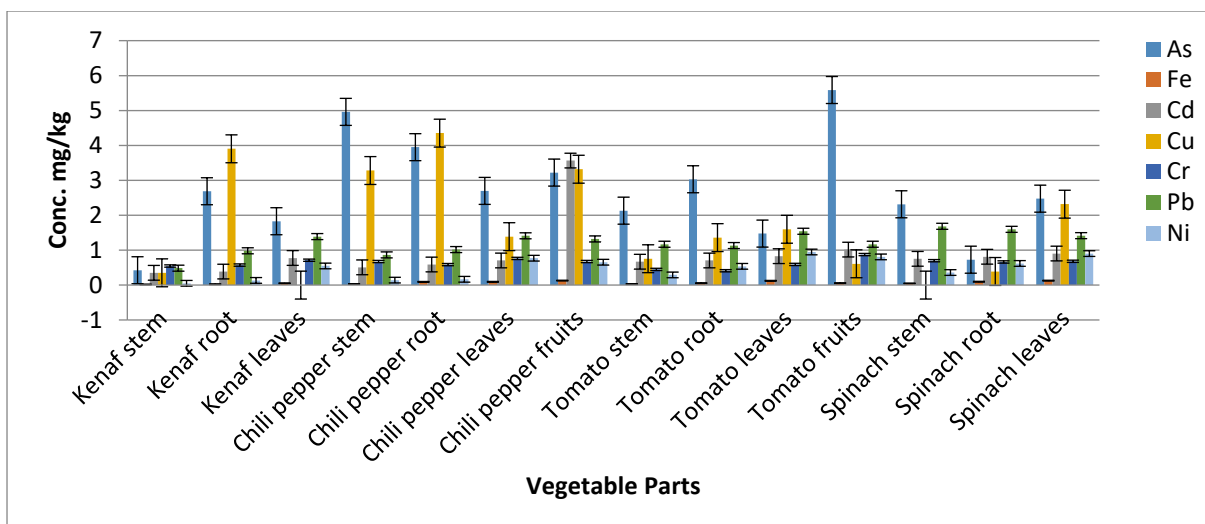
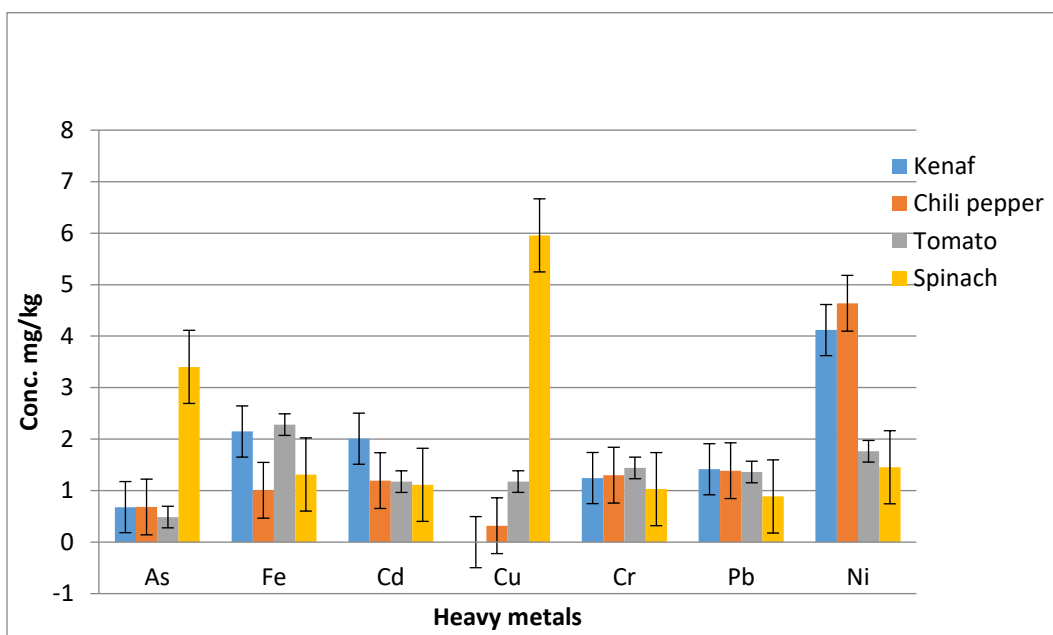


Fig.5 Bioaccumulation Factors (BAF) for Kenaf, Chili Pepper, Tomato and Spinach Different Parts.

Table 6: Translocation Factors (TF) for Kenaf, Chili Pepper, Tomato and Spinach Different Parts (Leaves/Root)

Samples	As	Fe	Cd	Cu	Cr	Pb	Ni
Kenaf	0.680	2.148	2.009	0.000	1.244	1.415	4.118
Chili pepper	0.683	1.007	1.195	0.319	1.301	1.387	4.639
Tomato	0.487	2.282	1.175	1.176	1.441	1.362	1.765
Spinach	3.403	1.314	1.113	5.956	1.029	0.887	1.454

TF >1 indicates efficient translocation



BTF >1 indicates efficient translocation

Fig.6 Translocation Factors (TF) for Kenaf, Chili Pepper, Tomato and Spinach Different Parts.

Table 7: Contamination Factor (CF) for Soil

Heavy Metal	Background Values	Soil Concentrations	CF	Contamination Level
Cr	0.10	0.116	1.16	Moderate
As	0.01	0.010	1.00	Low
Fe	1.0	10.62	10.62	Very High
Cd	0.01	0.083	8.30	Very High
Cu	1.3	0.105	0.08	Low
Pb	0.05	0.037	0.74	Low
Ni	0.2	0.331	1.66	Moderate

Background Values – WHO water standards

CF Classification: <1 (Low), 1-3 (Moderate), 3-6 (Considerable), >6 (Very High)

Table 8: Correlation Analysis for Kenaf, Chili Pepper, Tomato and Spinach Different Parts

	Kenaf stem	Kenaf root	Kenaf leaves	Soil	Water
Kenaf stem	1				
Kenaf root	0.44214	1			
Kenaf leaves	0.89741	0.2198	1		
Soil	0.94425	0.37492	0.957	1	
Water	0.90826	0.3123	0.99273	0.97578	1

	Chili pepper stem	Chili pepper root	Chili pepper leaves	Chili pepper fruits	Soil	Water
Chili pepper stem	1					
Chili pepper root	0.86915	1				
Chili pepper leaves	0.61028	0.90828	1			
Chili pepper fruits	0.69344	0.94717	0.96782	1		
Soil	0.57965	0.90587	0.97955	0.96643	1	
Water	0.51484	0.85588	0.9928	0.94777	0.97578	1

	Tomato stem	Tomato root	Tomato leaves	Tomato fruits	Soil	Water
Tomato stem	1					
Tomato root	0.9953	1				
Tomato leaves	0.9956	0.99475	1			
Tomato fruits	0.96181	0.96225	0.97069	1		
Soil	0.97093	0.96215	0.98079	0.92638	1	
Water	0.98247	0.97884	0.99271	0.98612	0.97578	1

	Spinach stem	Spinach root	Spinach leaves	Soil	Water
Spinach stem	1				
Spinach root	0.99287	1			
Spinach leaves	0.96246	0.9876	1		
Soil	0.97802	0.98936	0.98028	1	
Water	0.9884	0.99577	0.98426	0.97578	1

3.1 Discussion

Heavy Metal Concentrations in Kenaf Plant Parts

As presented in Table 1, heavy metal concentrations in kenaf (*Hibiscus cannabinus* L.) stems, leaves, and roots showed distinct accumulation patterns. All detected concentrations were below WHO permissible limits for vegetables. Among the metals, **iron (Fe)** was highest in the leaves (0.536 mg/kg), followed by nickel (Ni) at 0.181 mg/kg. This is consistent with [17], who highlighted kenaf's high biomass and potential for phytoremediation of heavy metals.

Interestingly, copper (Cu) was undetectable in leaves but accumulated significantly in the roots (0.408 mg/kg), supporting Li et al. (2022), who observed root retention mechanisms in kenaf for cadmium. The soil showed chromium (Cr) concentrations (0.116 mg/kg) slightly above the WHO permissible level (0.10 mg/kg), along with elevated iron (10.616 mg/kg) and cadmium (0.083 mg/kg) levels. Water samples also exhibited high arsenic (As) (0.014 mg/L) and cadmium (0.024 mg/L), exceeding WHO guidelines ($p < 0.05$), creating a contaminated environment from which kenaf absorbed these metals.

Heavy Metal Concentrations in Chili Pepper Plant Parts

Table 2 reveals notable heavy metal accumulation in chili pepper stems, roots, leaves, and fruits. Iron (Fe) concentrations were highest in fruits (1.358 mg/kg), with other parts also showing significant levels, although all remained below the WHO vegetable limit of 20 mg/kg. **Cadmium (Cd)** in fruits (0.295 mg/kg) exceeded the permissible threshold (0.2 mg/kg), raising health concerns. These findings align with [18], who reported high Cr and Pb concentrations in dried chili peppers from Guizhou Province.

Translocation patterns show Fe preferentially moving to fruits, while Cu accumulates in roots (0.455 mg/kg), suggesting metal-specific transport. [19] Cautioned against using edible crops for phytoremediation due to the risk of introducing heavy metals into the food chain—especially relevant here given the elevated Cd in the fruits.

Heavy Metal Concentrations in Tomato Plant Parts

According to Table 3, tomatoes demonstrated efficient translocation of heavy metals, especially to aerial parts. Leaves showed the highest Fe (1.292 mg/kg) and Ni (0.313 mg/kg) concentrations, while fruits contained arsenic (0.055 mg/kg), exactly within the WHO limit ($p < 0.05$), and cadmium (0.084 mg/kg), which is also within WHO standard limits. The metal distribution supports [20], who reported higher translocation of As, Cr, Ni, Mn, and Pb to leaves in vegetable crops. [21] Also emphasized that metal accumulation varies based on plant part and metal type. Tomato, in this study, showed a tendency to accumulate Cr (0.101 mg/kg) predominantly in the fruits.

Heavy Metal Concentrations in Spinach Plant Parts

As shown in Table 4, spinach exhibited a relatively balanced metal distribution, Fe concentration in leaves (1.345 mg/kg) and roots (1.024 mg/kg) are within WHO vegetables limits ($p < 0.05$). Cd in leaves (0.075 mg/kg) is within WHO limits. [22] Found that translocation factors vary by metal and plant species, which is supported here by efficient movement of metals to leaves—the edible part. [23] Noted that translocation factor (TF) is a critical measure of metal movement from roots to shoots. [19] Observed higher Cu, Fe, and Zn translocation to stems in spinach, although in this study, leaf concentrations were higher, possibly due to differing environmental or cultivation conditions.

Environmental Influence on Heavy Metal Uptake

Heavy metal concentrations in **soil and water** directly influenced uptake and accumulation in plant tissues. Soil arsenic (0.010 mg/kg) and water (0.014 mg/L) were both below WHO limits, yet plant tissues—especially chili pepper stems (0.049 mg/kg) and tomato fruits (0.055 mg/kg)—accumulated detectable amounts. This likely reflects arsenic's high mobility in oxidized environments [24]. Iron, while essential, showed high leaf accumulation despite moderate soil (10.616 mg/kg) and water (0.306 mg/L) levels, consistent with active Fe uptake mechanisms [25]. Waterborne cadmium (0.024 mg/L) exceeded WHO limits, and chili pepper fruits (0.295 mg/kg) showed high accumulation, possibly due to favorable translocation and rhizosphere conditions [26]. Copper and lead, though low in soil and water, accumulated in roots (kenaf, chili) and stems (spinach), reflecting metal-specific mobility and sequestration.

Bioaccumulation Factors (BAF)

As detailed in Table 5, BAF analysis highlights species- and metal-specific accumulation. Arsenic had the highest BAF values—most notably in tomato fruits (5.586) and chili stems (4.960)—suggesting hyperaccumulation [22]. Cadmium also showed high bioaccumulation in chili fruits (3.565), raising food safety concerns. Copper accumulated strongly in roots of chili (4.352) and kenaf (3.902), while iron showed consistently low BAFs (0.016–0.128), despite being essential. Lead exceeded the BAF threshold (>1) in all plant parts, with spinach stems (1.683) and chili leaves (1.410) being highest. Nickel accumulation was below the threshold in most parts, except in tomato and spinach leaves.

Translocation Factor (TF) and Contamination Factor (CF)

Data in Tables 6 and 7 show that nickel had the highest translocation efficiency, especially in chili (TF = 4.639) and kenaf (TF = 4.118). This supports its suitability for phytoremediation, as discussed by [27]. Iron showed strong leaf translocation in tomato (TF = 2.282) and kenaf (TF = 2.148), while chili exhibited low Fe TF (1.007) despite high fruit Fe accumulation. Cadmium was efficiently translocated in kenaf (TF = 2.009) and chili (TF = 1.195), correlating with high fruit Cd levels. Copper varied widely, with spinach showing a high TF (5.956) and kenaf showing no leaf translocation (TF = 0.000). Arsenic translocation was highest in spinach (TF = 3.403), despite low environmental levels (CF = 1.00), showing the influence of waterborne As uptake. Lead TFs were moderate across most plants (1.362–1.415), except in spinach (0.887), where Pb accumulated mainly in stems. In terms of contamination, Fe (CF = 10.62) and Cd (CF = 8.30) represented the most severe soil contamination levels, with serious implications for plant uptake and food safety. Moderate CFs were observed for Ni (1.66) and Cr (1.16), while As (1.00), Pb (0.74), and Cu (0.08) were within low contamination categories.

3.2. Correlation Analysis of Heavy Metal Concentrations in Kenaf, Tomato, Chili Pepper, and Spinach

The correlation analysis in Table 8 highlights the relationships between heavy metal concentrations in various plant parts, as well as their corresponding levels in soil and water, across four plant species: kenaf, chili pepper, tomato, and spinach. The correlation coefficients (r), which range from -1 to 1, indicate the strength and direction of these relationships—with values approaching +1 signifying strong positive correlations and those nearing -1 indicating strong negative associations.

Kenaf

- A strong positive correlation was observed between the stem and leaves ($r = 0.89741$), indicating that increases in metal concentration in the stem are reflected in the leaves.
- The correlation between kenaf stem and soil was very strong ($r = 0.94425$), suggesting a close relationship between soil contamination and metal uptake in the stem.

- Kenaf leaves and water also showed a very strong correlation ($r = 0.99273$), highlighting water as a significant contributor to heavy metal accumulation in the foliage.

Chili Pepper

- A strong positive correlation was found between the root and leaves ($r = 0.90828$), indicating internal consistency in heavy metal distribution between these parts.
- The fruits and soil exhibited a very strong correlation ($r = 0.96643$), implying that soil contamination significantly influences fruit contamination.
- The relationship between leaves and water was also very strong ($r = 0.99280$), underscoring the role of water in leaf accumulation of metals.

Tomato

- An extremely strong correlation was observed between the stem and root ($r = 0.99530$), suggesting near-identical metal concentrations in both parts.
- Leaves and fruits showed a strong positive correlation ($r = 0.97069$), indicating synchronized accumulation patterns between these edible parts.
- Tomato leaves and water also had a very strong correlation ($r = 0.99271$), reinforcing water's impact on metal uptake in foliage.

Spinach

- Stem and root metal concentrations showed an extremely strong correlation ($r = 0.99287$), signifying uniform accumulation between underground and supporting tissues.
- Spinach leaves and soil showed a strong positive correlation ($r = 0.98028$), suggesting that soil contamination directly affects leaf accumulation.
- Leaves and water also correlated strongly ($r = 0.98426$), further emphasizing water as a key pathway for heavy metal uptake in spinach.

Overall trends

Across all plant species, there is a consistent pattern of strong positive correlations between plant tissues and both soil and water heavy metal concentrations. This indicates that environmental sources—particularly soil and irrigation water—play critical roles in the bioavailability and uptake of heavy metals by plants. Additionally, strong inter-organ correlations (e.g., between roots and stems or between leaves and fruits) suggest that once absorbed, heavy metals tend to be distributed uniformly within the plant system. Particularly high correlations, such as those seen in tomato and spinach, point to the potential use of these species in phytoremediation, as they demonstrate efficient accumulation and internal transport of heavy metals from contaminated environments.

4. Conclusion

The study confirms the presence of heavy metal contamination in Gobbiya Dam agricultural ecosystem. While most metal concentrations in soil and water were within permissible limits, cadmium and arsenic levels in irrigation water and plant tissues were above WHO-recommended thresholds. The vegetable species differed in their accumulation tendencies: chili pepper and tomato fruits posed the greatest food safety risks due to high Cd and As content. Bioaccumulation and translocation assessments indicated that certain vegetables, notably tomato and spinach, efficiently translocate metals to edible parts. The findings highlight the need for routine environmental monitoring, public health risk assessment, and implementation of phytoremediation or source-control interventions.

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