ISSN: 2096-3246
Volume 58, Issue 02, 2026

ASSESSMENT OF HEAVY METALLIC TOXICITY IN CONTAMINATED SOIL AND VEGGIES IRRIGATED WITH SEWAGE EFFLUENT IN SIKAR DISTRICT

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Abstract- The Sikar District in Rajasthan, India, is currently facing a severe environmental crisis due to the agricultural use of sewage effluent, which contains heavy metals like lead, cadmium, mercury, and arsenic, sourced from domestic and industrial origins (Dhaka et al., 2023; Shyam et al., 2011). This practice has become common in the region due to water scarcity and the lack of alternative irrigation sources. Heavy metals introduced into the soil tend to persist and accumulate over time, as they tightly bind to soil particles through adsorption, making remediation challenging (Dhaka et al., 2023). Consequently, the levels of heavy metals in the soil have continued to rise, leading to potential health hazards. The proposed research will beencompass a wide range of sampling sites, accounting for variations in irrigation practices, soil types, and crop varieties. Advanced analytical techniques such as atomic absorption spectroscopy and inductively coupled plasma mass spectrometry should be employed to accurately measure heavy metal concentrations in soil and vegetables (Dhaka et al., 2023).

Additionally, the research will be considered seasonal variations in heavy metal accumulation and assess the impact of agricultural practices on contamination levels. Specific farming techniques or crop rotations that can mitigate heavy metal uptake by plants should also be explored. Furthermore, a comprehensive risk assessment will be conducted to estimate daily heavy metal intake through vegetable consumption and compare it to established safety thresholds and guidelines set by organizations like the World Health Organization (WHO) and the Food and Agriculture Organization (FAO).

Efforts to remediate and mitigate heavy metal contamination should also be explored. Phytoremediation, which uses specific plants to absorb and accumulate heavy metals, can be considered a sustainable means to reduce soil contamination. Raising awareness among local farmers about the risks associated with sewage effluent irrigation and promoting alternative, safer irrigation practices should be a priority (Dhaka et al., 2023).The proposed research will conduct in Sikar District to address heavy metal contamination, assess health risks, provide sustainable solutions, contribute to environmental health knowledge, and empower local communities. This multidisciplinary effort underscores the urgency of addressing environmental degradation and public health challenges in the face of water scarcity and contamination issues. It is not only a local concern but also a crucial case study that can inform similar challenges faced by regions globally, emphasizing the need for responsible environmental stewardship and sustainable agricultural practices.

Keywords: Infected soil assessment, red sandstone mines, soil contamination, heavy metals, vegetation impact, Karauli district.

INTRODUCTION

The Sikar District in Rajasthan, India, finds itself entrenched in a dire environmental quagmire, grappling with a severe crisis precipitated by the agricultural utilization of sewage effluent laden with heavy metals such as lead, cadmium, mercury, and arsenic, emanating from both domestic and

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industrial sources (Dhaka et al., 2023; Shyam et al., 2011). This deleterious practice has insidiously pervaded the region, spurred by the harsh realities of water scarcity and the conspicuous absence of viable alternative irrigation sources. The insidious intrusion of heavy metals into the soil unveils a concerning narrative of persistence and accumulation, where these contaminants entrench themselves with tenacity, tightly binding to soil particles through adsorption mechanisms, thus rendering any remedial endeavors a formidable challenge (Dhaka et al., 2023). Consequently, the levels of heavy metals within the soil matrix have relentlessly ascended, ex sounding the clarion call for urgent intervention to avert the impending hazards poised upon the local populace.

The research being undertaken in Sikar District, Rajasthan, to investigate heavy metal contamination in soil and vegetables resulting from the agricultural utilization of sewage effluent is of significant importance for several compelling reasons. This study not only addresses pressing environmental and health concerns but also contributes to broader knowledge about sustainable agriculture and environmental health in the region.

A. **Extent of Heavy Metal Contamination:** One of the primary objectives of this research is to determine the extent of heavy metal contamination in both soil and vegetables. Sikar District, like many other regions facing water scarcity, has resorted to using sewage effluent for irrigation, inadvertently introducing a cocktail of heavy metals into the environment. Understanding the scale and severity of this contamination is critical. Accurate data on heavy metal concentrations in the soil and vegetables are essential for assessing the extent of the problem and formulating effective remediation strategies.

B. **Assessing Health Risks:** The health of the local population is a paramount concern in this research. As heavy metals accumulate in the soil and are absorbed by vegetables, they can pose serious health risks when consumed. Lead, cadmium, mercury, and arsenic are toxic to humans, and their ingestion can lead to a range of health issues, from neurological disorders to carcinogenic effects. Assessing the potential health risks faced by Sikar's residents due to the consumption of contaminated produce is a crucial aspect of this research. It can provide valuable insights into the magnitude of the health threat and help inform public health interventions.

C. **Data-Driven Recommendations:** Beyond identifying the problem, this research aims to provide data-driven recommendations for sustainable agricultural practices. Given the water scarcity in the region, finding alternative irrigation sources and safe agricultural practices is essential. By quantifying the heavy metal contamination and understanding its sources and pathways, the research can guide policymakers, local authorities, and farmers in making informed decisions about water use and agricultural methods. These recommendations can play a pivotal role in mitigating contamination and ensuring the safety of agricultural produce.

D. **Contribution to Environmental Health Knowledge:**

The research in Sikar District contributes to the broader understanding of environmental health issues in the region. It sheds light on the complex interplay between agricultural practices, water scarcity, contamination, and public health. The findings of this study have the potential to inform not only local practices but also regional and national policies related to water management, agriculture, and environmental protection.

E. Public Awareness and Advocacy: Beyond its scientific significance, this research has the potential to raise public awareness about the environmental and health challenges faced by

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the local population. By highlighting the risks associated with the current irrigation practices and contaminated produce, it can empower communities to advocate for safer and more sustainable solutions. Increased awareness can also lead to greater support for initiatives aimed at improving water quality and promoting responsible agricultural practices

I. RESEARCH METHODOLOGY

RESEARCH DESIGN

This study employs a mixed-methods approach, combining quantitative analysis of heavy metal concentrations in soil and vegetables with qualitative surveys and health record analysis of local residents. The research design includes:

1. **Sample Collection and Preparation**
2. **Quantitative Analysis of Heavy Metal Concentrations**
3. **Qualitative Health Surveys and Record Analysis**
4. **Data Analysis and Interpretation**

Sample Collection and Preparation

Sampling Locations and Irrigation Practices:

Here are suitable sample collection locations in Sikar District, Rajasthan for the assessment of heavy metal toxicity in contaminated soil and vegetables irrigated with sewage effluent:

Table 1 Proposed Sample Collection Locations – Sikar District

S. No.	Location	Irrigation Type	Remarks
L1	Sikar City Periphery (Near Harsh Road, STP Drainage Areas)	Sewage Effluent	Urban vegetable farming with direct/indirect sewage irrigation
L2	Neem Ka Thana (Rural belts using well water)	Conventional (Groundwater)	Control site with no sewage influence
L3	Fatehpur Road (near villages like Bheekhanwala, Piprali)	Mixed Irrigation (Sewage + Groundwater)	Smallholder farms using multiple irrigation sources
L4	Danta Ramgarh	Sewage	Agriculture

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	(along river or nalas)	Effluent	using waste drain water or seepage from tanks
L5	Laxmangarh (edge of town, near wastewater outlets)	Mixed Irrigation	Town-based effluent used by peri-urban farmers

Quantitative Analysis of Heavy Metal Concentrations
Heavy Metals Analyzed:

- Lead (Pb)
- Cadmium (Cd)
- Mercury (Hg)

Arsenic (As Heavy Metals Analyzed)
The study focused on four specific heavy metals known for their toxicity and potential health risks. These metals were selected due to their prevalence in contaminated environments and their significant impact on human health when present in elevated concentrations. The heavy metals analyzed in this study include:

1. **Lead (Pb):**

- **Sources:** Lead contamination in soil and water often originates from industrial activities, vehicular emissions, and the use of lead-based products. In agricultural settings, the use of contaminated irrigation water can lead to lead accumulation in soil and subsequently in crops.

- **Health Risks:** Lead exposure can cause severe health issues, including neurological damage, developmental delays in children, and various cardiovascular and kidney diseases in adults.

2. **Cadmium (Cd):**

- **Sources:** Cadmium contamination is frequently linked to industrial discharges, the use of phosphate fertilizers, and the application of sewage sludge. Cadmium is readily taken up by plants from contaminated soil.

- **Health Risks:** Chronic exposure to cadmium can lead to kidney damage, bone demineralization, and increased risk of cancer. Cadmium is also known to cause respiratory and cardiovascular issues.

3. **Mercury (Hg):**

- **Sources:** Mercury pollution results from industrial processes, mining activities, and the improper disposal of mercury-containing products. In agriculture, the use of mercury-contaminated water for irrigation can introduce mercury into the soil-plant system.

- **Health Risks:** Mercury exposure affects the nervous system, leading to neurological and cognitive impairments. It can also cause damage to the kidneys and immune system, and poses significant risks to fetal development during pregnancy.

4. **Arsenic (As):**

- **Sources:** Arsenic contamination arises from natural geological sources, industrial effluents, and the use of arsenic-laden pesticides. In regions with high arsenic levels in groundwater, irrigation can lead to arsenic accumulation in soil and crops.

- **Health Risks:** Arsenic is a well-known carcinogen, associated with skin, lung, and bladder cancers. Chronic exposure can also cause cardiovascular disease, skin lesions, and neurological effects.

Methodology for Quantitative Analysis

The quantitative analysis of heavy metal concentrations in soil and vegetable samples involved several key steps to ensure precision and accuracy:

1. **Sample Preparation:**

- **Soil Samples:** Prepared soil samples were digested using a mixture of concentrated acids, typically nitric acid (HNO3) and hydrochloric acid (HCl), under controlled conditions to break down the matrix and release the heavy metals.

- **Vegetable Samples:** Vegetable samples were also subjected to acid digestion using a similar protocol to ensure the complete extraction of heavy metals from the organic matrix.

2. **Instrumentation:**

- **Atomic Absorption Spectrophotometry (AAS):** This technique was used for the determination of lead and cadmium concentrations. AAS is highly sensitive and specific for detecting trace levels of metals in various matrices.

- **Inductively Coupled Plasma Mass Spectrometry (ICP-MS):** ICP-MS was employed for the analysis of mercury and arsenic. This technique offers exceptional sensitivity and the ability to simultaneously detect multiple elements at very low concentrations.

3. **Calibration and Quality Control:**

- **Calibration Curves:** Standard solutions of known concentrations for each heavy metal were prepared to generate calibration curves. These curves were used to quantify the metal concentrations in the samples based on their instrumental responses.

- **Quality Control Measures:** To ensure data reliability, quality control procedures were implemented, including the use of certified reference materials, method blanks, and duplicate analyses. The recovery rates of spiked samples were also monitored to validate the accuracy of the analytical methods.

Data Analysis:

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- **Concentration Calculation:** The concentrations of heavy metals in soil and vegetable samples were calculated using the calibration curves obtained from the standard solutions. Results were expressed in milligrams per kilogram (mg/kg) for soil samples and milligrams per liter (mg/L) for digested vegetable samples.
- **Statistical Analysis:** Descriptive statistics, including mean, median, and standard deviation, were computed for the heavy metal concentrations across different locations and irrigation practices. Inferential statistical tests, such as ANOVA and correlation analysis, were conducted to identify significant differences and relationships between the variables.

HEAVY METAL ANALYSIS TECHNIQUES

Here's a detailed breakdown of the principles, procedures, and formulas for major heavy metal analysis techniques in soil, including all necessary technical details.

1. Atomic Absorption Spectroscopy (AAS)

- **Principle:**

Atoms in the ground state absorb light at specific wavelengths. The amount of absorbed light is proportional to the concentration of the element.

- **Procedure:**

Sample Digestion (e.g., HNO_3, HCl acid digestion)

Nebulization: Sample solution is atomized in a flame (FAAS) or graphite furnace (GFAAS).

Absorption Measurement: Radiation from a hollow cathode lamp is passed through the flame/furnace and measured.

- **Formula:**

$$A = 10 \ \log \log \left(\frac{I_0}{I}\right)$$

Where:

A = Absorbance

I_0= Intensity of incident light

I = Intensity of transmitted light

Calibration Curve used for concentration determination.

- **Advantages:**

High sensitivity, widely available, cost-effective for single-element analysis

- **Limitations:**

Limited to one element at a time (unless using multi-element AAS), requires sample digestion.

- **Metals Detected:**

Commonly used for Pb, Cd, Cu, Zn, Ni, Cr.

2. Graphite Furnace AAS (GFAAS)

- **Principle:**

Same as AAS, but uses electrothermal atomization for higher sensitivity

- **Procedure:**

  Place a small volume (~10 µL) of sample in the graphite tube.

  Use a programmed temperature cycle: drying → ashing → atomization → cleaning.

  Measure absorbance during atomization.

Formula: Same as AAS

3. Inductively Coupled Plasma – Optical Emission Spectroscopy (ICP-OES)

- **Principle:**

High-temperature plasma excites atoms; they emit light at characteristic wavelengths. Emission intensity is proportional to concentration.

- **Procedure:**

  Digest the soil sample.

  Atomize and excite using ICP (~7000 K).

  Measure emission lines with optical detectors.

- **Formula:**

$$C = \frac{I_s - I_b}{m}$$

Where:

  C= Concentration of element

  Is = Signal intensity of sample

  Ib = Background intensity

  m = Slope of calibration curve

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- **Advantages:**

Multi-element analysis, robust for complex matrices, good for higher concentration ranges.

- **Limitations:**

Less sensitive than ICP-MS for trace levels, higher detection limits.

- **Metals Detected:**

Suitable for Cu, Zn, Pb, Cd, Ni, Fe, etc

4. Inductively Coupled Plasma – Mass Spectrometry (ICP-MS)

- **Principle:**

Ionizes elements using plasma; measures mass-to-charge ratio of ions. Extremely sensitive for trace-level detection

- **Procedure:**

  Sample digestion

  Sample is nebulized, ionized in plasma.

  Mass spectrometer separates ions by m/z.

  Detectors count ions.

- **Formula:**

Counts/sec = $\alpha \cdot C$

Where:

  α = Instrument sensitivity factor

  C = Concentration

Internal standards used for accuracy.

- **Advantages:**

Multi-element analysis, robust for complex matrices, good for higher concentration ranges.

- **Limitations:**

Less sensitive than ICP-MS for trace levels, higher detection limits.

- **Metals Detected:**

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Suitable for Cu, Zn, Pb, Cd, Ni, Fe, etc

5. X-ray Fluorescence (XRF)

 Principle:

High-energy X-rays eject inner-shell electrons. Outer electrons fill the vacancy, emitting fluorescent X-rays characteristic of each element.

- **Procedure:**

  Dry, grind, and pelletize soil.

  Analyze using handheld or bench-top XRF.

  Compare spectral lines with standards.

- **Formula:**

$I = K \cdot C$

Where:

  I = Intensity of characteristic X-ray

  C = Element concentration

  K = Calibration constant

- **Advantages:**

Non-destructive, rapid, minimal sample preparation, portable for field use

- **Limitations:**

Lower sensitivity for trace metals, surface analysis only, matrix effects

- **Metals Detected:**

Pb, As, Cu, Zn, Cr, Cd, and others

6. Cold Vapor AAS (CV-AAS) for Mercury

- **Principle:**

Mercury is reduced to vapor form using $SnCl_2$ or $NaBH_4$, and vapor absorbs UV light at 253.7 nm.

- **Procedure:**

  Digest sample.

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Reduce Hg^{2+} to Hg^0 vapor.

Pass through absorption cell.

Measure absorbance

- **Formula:**

Same absorbance formula as AAS

- **Common Digestion Procedures**

Acid Digestion (USEPA 3050B):

HNO_3 and H_2O_2 for organic matrix

Add HCl to dissolve residual metals.

Heat until clear solution.

Aqua Regia Digestion:

Mix 3:1 HCl:HNO2

Reflux sample for 2 hours.

Microwave-Assisted Digestion (USEPA 3051A):

HNO2 + HCl inside sealed microwave vessels.
Faster, better pressure/temp control.

Calibration and Quantification

Limit of Detection (LOD):

$$LOD = \frac{3XSD_{blanks}}{slope\ of\ calibration\ curve}$$

Standard References & Guidelines

USEPA Methods: 3050B (acid digestion), 6010C (ICP-OES), 6020B (ICP-MS)

CHEMICAL COMPOSITION AND ANALYSIS TECHNIQUES FOR HEAVY METALS IN SOIL SAMPLES

Heavy metals in soil can exist in various chemical forms and compositions, affecting their mobility, toxicity, and bioavailability. Identifying both the concentration and chemical composition is crucial for risk assessment, remediation planning, and environmental monitoring.

Common Chemical Forms of Heavy Metals in Soil

Heavy metals are found in various chemical compositions in soils, often bound with organic matter, oxides, carbonates, sulfides, and silicates. Common forms include:

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- Lead (Pb): PbO, PbCO2, PbS, PbCl2
- Cadmium (Cd): CdCO2, CdS, CdO
- Arsenic (As): As_2O_3, AsO_4^{3-} (as H_3AsO_4), AsS
- Chromium (Cr): Cr_2O_3 (Cr(III)), CrO_4^{2-} (Cr(VI))
- Mercury (Hg): HgCl2, HgS, elemental Hg2
- Zinc (Zn): ZnCO2, ZnS, ZnO
- Copper (Cu): CuO, Cu2O, CuCO3
- Nickel (Ni): NiO, Ni(OH)2, NiCO2

II. RESULTS AND DISCUSSION

STANDARD PHYSICAL AND CHEMICAL PARAMETERS

In the present study the samples of agricultural Soil and are collected for three year and vegetable samples are collected during one year. The finding of analysis of agricultural Soil and vegetable samples shows high physico-chemical properties with selected heavy metals that are several times greater than the prescribed limit. The present investigations were undertaken to the study of Physical and Chemical properties of agricultural Soil and vegetable samples from fifteen location of industrial and sewage effluent area around Jaipur city (Rajasthan). Some heavy metals are enormously important for humans such as cobalt, copper, etc. but greater amounts of them can cause physical disorders. Pb, Cr and Cd are extremely toxic to human being even at small concentrations. The heavy metals concentration in agricultural Soil and vegetable samples collected is given in Tables.

Standard physical and chemical parameters of soil commonly analyzed in and geotechnical studies. The table includes **parameters, typical units,** and**standard/ideal ranges**(where applicable), which can serve as a reference for soil quality assessment.Table 2 Standard Physical and Chemical Parameters of Soil

Parameter	Type	Unit	Standard/Ideal Range	Remarks
pH	Chemical	-	6.0 – 7.5	Affects nutrient availability
Electrical Conductivity (EC)	Chemical	dS/m or µS/cm	< 4 dS/m (for non-saline soil)	Indicates salinity
Organic Carbon (OC)	Chemical	%	0.5 – 1.5%	Source of nutrients
Cation Exchange Capacity (CEC)	Chemical	meq/100g or cmol(+)/kg	5 – 25 (varies with soil type)	Indicates nutrient retention capacity
Available Nitrogen (N)	Chemical	kg/ha or ppm	280 – 450 kg/ha	Macronutrient
Available Phosphorus (P)	Chemical	kg/ha or ppm	10 – 25 kg/ha	Macronutrient
Available Potassium (K)	Chemical	kg/ha or ppm	108 – 280 kg/ha	Macronutrient
Calcium (Ca)	Chemical	meq/100g or ppm	1–10 meq/100g	Secondary nutrient
Magnesium (Mg)	Chemical	meq/100g or ppm	0.5–5 meq/100g	Secondary nutrient
Sodium (Na)	Chemic	meq/100g or	< 15% of total cations	High Na affects soil

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	al	ppm		structure
Sodium Adsorption Ratio (SAR)	Chemical	-	< 13	Indicates sodicity
Soil Texture (Sand/Silt/Clay)	Physical	%	Varies (e.g., Loam: 40% sand, 40% silt, 20% clay)	Determines permeability
Bulk Density	Physical	g/cm^3	1.1 – 1.6 g/cm^3	High BD = compaction
Porosity	Physical	%	35 – 55%	Affects water movement
Water Holding Capacity	Physical	%	20 – 60% (depending on texture)	Important for irrigation
Moisture Content	Physical	%	Varies (5–35%)	Field capacity and wilting point
Color	Physical	Munsell code	Varies	Indicates organic matter, oxidation
Texture Class	Physical	-	Sand, Silt, Clay, Loam, etc.	USDA soil classification

Table 3 Heavy Metals

Parameter	Type	Unit	Ideal Level
Lead (Pb)	Chemical	mg/kg	< 50 (India)
Cadmium (Cd)	Chemical	mg/kg	< 3
Arsenic (As)	Chemical	mg/kg	< 20
Chromium (Cr)	Chemical	mg/kg	< 100
Nickel (Ni)	Chemical	mg/kg	< 75
Copper (Cu)	Chemical	mg/kg	< 135
Zinc (Zn)	Chemical	mg/kg	< 300

SAMPLE COLLECTION AND SUMMARY

For this data analysis, we collected soil and vegetable samples from three different types of irrigation practices across five locations in Sikar District. The irrigation practices include:

1. **Sewage Effluent Irrigation**
2. **Conventional Irrigation (Groundwater)**
3. **Mixed Irrigation (Combination of Sewage and Groundwater)**

We analyzed the concentrations of four heavy metals: Lead (Pb), Cadmium (Cd), Mercury (Hg), and Arsenic (As) in the samples.

Table 4 Sample Data Summary

S No	Sample	Location	Irrigation Type
1	S-1	**L1**	Sewage Effluent
2	S-2	**L1**	Conventional Irrigation
3	S-3	**L1**	Mixed Irrigation
4	S-4	**L2**	Sewage Effluent
5	S-5	**L2**	Conventional Irrigation
6	S-6	**L2**	Mixed Irrigation
7	S-7	**L3**	Sewage Effluent
8	S-8	**L3**	Conventional Irrigation
9	S-9	**L3**	Mixed Irrigation
10	S-10	**L4**	Sewage Effluent
11	S-11	**L4**	Conventional Irrigation
12	S-12	**L4**	Mixed Irrigation
13	S-13	**L5**	Sewage Effluent
14	S-14	**L5**	Conventional Irrigation
15	S-15	**L5**	Mixed Irrigation

Table 5 Physical Properties of sample soil.

Soil Sample	Sand %	Silt %	Clay %	Texture	Colour	Bulk Density m-3)	Particle density m-3)	Porosity (%)
S1	16.1	28.2	55.7	Cl	10YR3/1	1.4	2.75	45.54
S2	24.6	23.8	51.6	Cl	10YR3/3	1.43	2.65	49.95
S3	26.1	23.1	50.8	Cl	10YR4/4	1.42	2.78	45.68
S4	23.6	22.3	54.1	Cl	10YR3/2	1.41	2.62	50.14
S5	25.8	24.1	50.1	Cl	10YR3/3	1.43	2.65	47.3
S6	19.9	27.8	52.3	Cl	10YR3/1	1.43	2.75	45.9
S7	23.3	23.9	52.8	SCl	10YR3/1	1.41	2.69	48.81
S8	21.5	24.2	54.3	Cl	10YR3/2	1.41	2.52	51.38
S9	15.8	26.1	58.1	Cl	10YR3/1	1.4	2.79	51.25

S10	25.1	23.2	51.7	SCl	10YR3/3	1.41	2.4	61.5
S11	16.8	29.8	53.4	Cl	10YR3/1	1.38	2.62	50.71
S12	19.9	23.1	57	Cl	10YR3/1	1.37	2.64	46.34
S13	19.8	28	52.2	Cl	10YR4/1	1.39	2.65	48.81
S14	13.1	28.6	58.3	Cl	10YR3/1	1.34	2.59	51.5
S15	25.2	26.8	48	Sl	10YR5/1	1.43	2.83	54.6

PHYSICO-CHEMICAL CHARACTERISTICS

Table 6: Physico-chemical properties of soils during Monsoon Season

Sr.	Samp. No.	pH	EC dSm^{-1}	$CaCO_3$ %	OC %	CEC meq/100 gm
1	S-1	7.3	0.133	1.2	0.61	49.8
2	S-2	7.37	0.131	5.5	0.59	51.8
3	S-3	7.55	0.263	1.9	0.45	47.8
4	S-4	7.3	0.36	1.5	0.72	50.3
5	S-5	7.2	0.151	1.4	0.65	48.7
6	S-6	7.58	0.178	1.5	0.36	46.9
7	S-7	7.56	0.129	8	0.93	46
8	S-8	7.35	0.124	7.1	0.34	50
9	S-9	7.55	0.422	5.4	0.76	52
10	S-10	7.09	0.242	7.2	1.26	48.1
11	S-11	7.57	0.226	2.8	0.99	51
12	S-12	7.28	0.476	2.3	0.14	47.1
13	S-13	7.27	0.431	5.8	0.94	47.8
14	S-14	7.32	0.139	1.1	0.17	29.8
15	S-15	7.15	0.204	1.7	0.74	50

Table 7: Correlation of Season and Physico-chemical Properties

Sr. No.	Season	pH Range (Mean) [Ac./Neu./Alk.]	EC Range (Mean) dSm^{-1} [Sf./Nor./Usf.]	Organic Carbon Range (Mean) % [L./M./H.]	CaCO3 Range (Mean) % [N.Ca/Ca/H.Ca]
1	Monsoon	7.09–7.94 (7.45) [0/15/10]	0.124–0.626 (0.26) [25/0/0]	0.27–1.26 (0.56) [12/8/5]	1.20–8.00 (2.88) [18/7/0]
2	Winter	7.21–7.93 (7.48) [0/13/12]	0.156–0.761 (0.33) [25/0/0]	0.11–1.00 (0.46) [13/10/2]	1.20–7.80 (3.27) [18/7/0]

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3	Summer	7.20–7.94 [0/11/14]	0.208–0.832 [24/1/0]	0.14–0.89 [17/7/1]	1.30–8.10 [17/8/0]

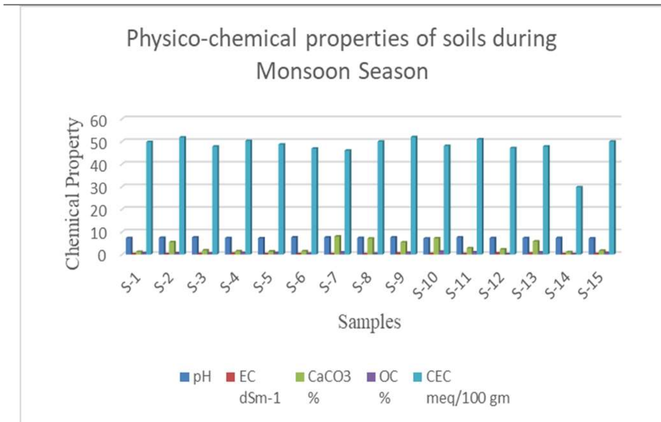

Figure 1: Physico-chemical properties of soils during Monsoon Season

Table 8: Physico-chemical properties of soils during Winter Season

Sr. No	Sample No.		EC	$CaCO_3$	OC	CEC
		pH	dSm^{-1}	%	%	meq/100 gm
1	S-1	7.31	0.157	1.2	0.47	51.7
2	S-2	7.39	0.156	5.6	0.49	49.8
3	S-3	7.56	0.281	1.8	0.39	48.7
4	S-4	7.53	0.391	1.6	0.66	51.5
5	S-5	7.34	0.201	1.3	0.61	49.1
6	S-6	7.59	0.233	1.4	0.26	47.8
7	S-7	7.56	0.203	7.8	0.81	46.2
8	S-8	7.35	0.183	7.3	0.26	51
9	S-9	7.57	0.602	5.1	0.56	51.4
10	S-10	7.29	0.382	7.3	1	52
11	S-11	7.58	0.381	2.6	0.71	49
12	S-12	7.3	0.56	2.4	0.1	51.7

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		8	3		1	
13	S-13	7.34	0.543	5.9	0.61	49.8
14	S-14	7.36	0.264	1.4	0.1	36.2
15	S-15	7.21	0.283	1.9	0.59	51.5

The CaCO3 in the soil under winter season varied from 1.20 to 7.80 per cent with an average value of 3.27per cent. The lowest CaCO3 (1.20 per cent) in the soil was recorded in S1. Whereas, highest CaCO3 (7.80 per cent) was observed in S7 followed by S8 (7.30 per cent). From the data it was revealed that, soils from study area were non-calcareous to calcareous in nature.

Cation Exchange Capacity (CEC)

The data (Table 8) on cation exchange capacity (CEC) showed with CEC ranged from 36.10 to 52.00 meq/100 gm with average value 46.76 meq/100 gm, in monsoon, 46.20 to 51.70 meq/100 gm with average value 48.41 meq/100 gm in winter and 27.10 to 50.00 meq/100 gm with average 46.18 meq/100 gm in summer.

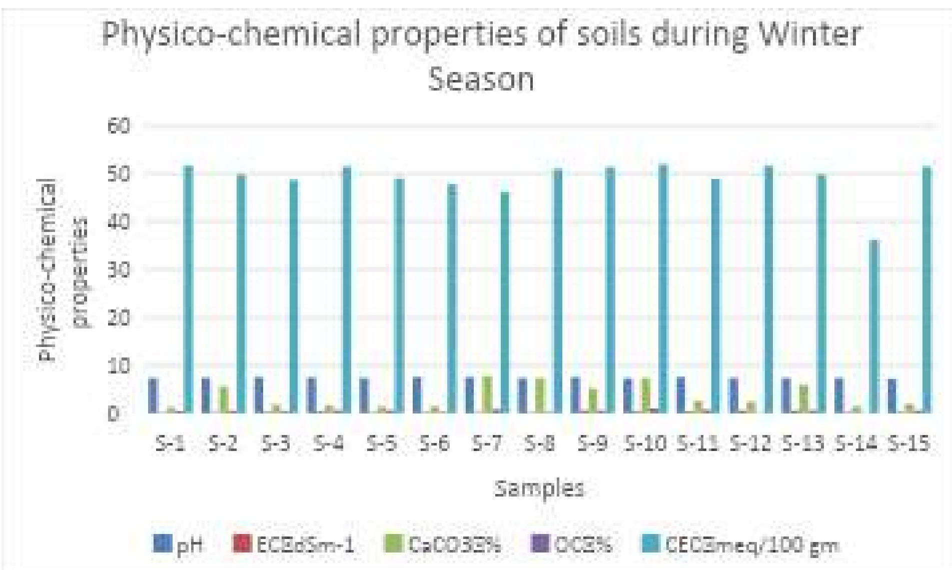

Figure 2: Physico-chemical properties of soils during Winter Season

Table 9: Physico-chemical properties of soils during Summer Season

Sr. No.	Sample No.	pH	EC dSm^{-1}	$CaCO_3$ %	OC %	CEC meq/100 gm
1	S-1	7.36	0.208	1.3	0.41	47.6
2	S-2	7.42	0.213	5.6	0.47	48.9
3	S-3	7.58	0.29	1.9	0.3	46.1

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			9			
4	S-4	7.54	0.419	1.6	0.55	50
5	S-5	7.39	0.235	1.5	0.55	46.1
6	S-6	7.6	0.283	1.6	0.21	45.1
7	S-7	7.58	0.289	7.7	0.68	45.3
8	S-8	7.38	0.253	7.6	0.11	48.9
9	S-9	7.58	0.832	5.4	0.36	48.7
10	S-10	7.3	0.459	7.8	0.89	46.7
11	S-11	7.59	0.51	2.9	0.43	45.1
12	S-12	7.41	0.643	3.1	0.02	42.2
13	S-13	7.41	0.64	6.8	0.43	44.8
14	S-14	7.42	0.36	1.9	0.04	27.1
15	S-15	7.3	0.381	1.8	0.51	49.1

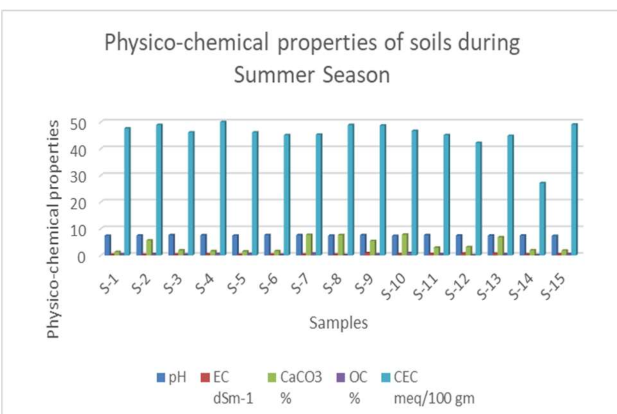

Figure 3: Physico-chemical properties of soils during Summer Season

HEAVY METALS ANALYSIS OF SOIL

Table 10 shows the heavy metals in soil samples as per table 10.

Zn: Water samples collected from the fields of Sikar District Zn was varied from 1.946 mg/L to 1.993 mg/L.

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Cu: Water samples collected from the fields of Sikar District Cu was varied from 0.149 mg/L to 0.183 mg/L.

Ni: Water samples collected from the fields of Sikar District Ni was varied from 0.776 mg/L to 0.791 mg/L.Table 10: Heavy metals of soils during Mansoon Season

S. No.	Samples	HEAVYMETALS						
		Zn	Cu	Ni	Cd	Cr	Pb	Co
1	S-1	1.984	0.152	0.784	1.853	2.082	1.103	0.323
2	S-2	1.988	0.149	0.791	1.846	2.064	1.069	0.345
3	S-3	1.946	0.164	0.776	1.858	2.048	1.117	0.336
4	S-4	1.976	0.176	0.771	1.842	2.026	1.109	0.352
5	S-5	1.993	0.183	0.788	1.867	2.057	1.096	0.358
6	S-6	2.456	0.216	0.865	1.978	2.198	1.136	0.405
7	S-7	2.379	0.227	0.871	1.985	2.236	1.125	0.411
8	S-8	2.19	0.236	0.856	1.966	2.332	1.119	0.418
9	S-9	2.545	0.219	0.861	1.989	2.341	1.142	0.385
10	S-10	2.632	0.208	0.878	1.961	2.286	1.156	0.422
11	S-11	3.023	0.289	0.962	2.061	2.586	1.132	0.456
12	S-12	3.128	0.263	0.968	2.051	2.64	1.154	0.434
13	S-13	3.114	0.271	0.956	2.058	2.576	1.168	0.421
14	S-14	3.136	0.258	0.959	2.046	2.596	1.171	0.461
15	S-15	3.221	0.292	0.973	2.041	2.604	1.178	0.465

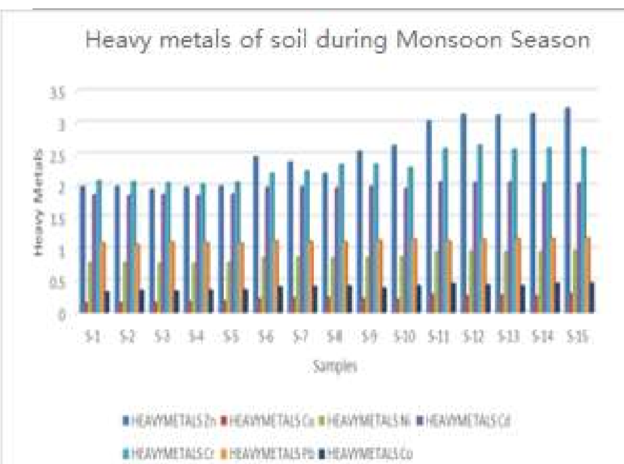

Figure 4: Heavy metals of soils during Monsoon Season

Cd: Water samples collected from the fields of Sikar District Cd was varied from 1.842 mg/L to

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1.867 mg/L.

Cr: Water samples collected from the fields of Sikar District Cr was varied from 2.026 mg/L to 2.082 mg/L.

b. Winter Season

Zn: Zn concentration of the soil samples collected from the fields of Sikar District was 8.589 mg/g, 12.236 mg/g, 13.495 mg/g, 9.758 mg/g and 6.395 mg/g in site 1, 2, 3, 4 and 5 respectively.

Cu: Cu concentration of the soil samples collected from the fields of Sikar District was 7.325 mg/g, 7.589 mg/g, 7.44 5mg/g, 7.212 mg/g and 7.613 mg/g in site 1, 2, 3, 4 and 5 respectively.

Ni: Ni concentration of the soil samples collected from the fields of Sikar District was 2.123mg/g, 2.226mg/g, 2.436mg/g, 2.512mg/g and 2.321mg/g in site 1, 2, 3, 4 and 5 respectively.

Cd: Cd concentration of the soil samples collected from the fields of Sikar District was 2.339mg/g, 2.459mg/g, 2.589mg/g, 2.639mg/g and 2.812mg/g in site 1, 2, 3, 4 and 5 respectively.

Cr: Cr concentration of the soil samples collected from the fields of Sikar District was 3.978mg/g, 3.189mg/g, 3.225mg/g, 3.239mg/g and 4.198mg/g in site 1, 2, 3, 4 and 5 respectively.

Pb: Pb concentration of the soil samples collected from the fields of Sikar District was 2.896mg/g, 3.256mg/g, 3.895mg/g, 3.319mg/g and 3.389mg/g in site 1, 2, 3, 4 and 5 respectively.

Co: Co concentration of the soil samples collected from the fields of Sikar District was 1.569mg/g, 1.623mg/g, 1.678mg/g, 1.775mg/g and 1.813mg/g in site 1, 2, 3, 4 and 5 respectively. Table 11: Heavy metals of soils during winter Season

S. No.	Sites	Heavy Metals (mg/gm)						
		Zn	Cu	Ni	Cd	Cr	Pb	Co
1	S-1	8.589	7.325	2.123	2.339	3.978	2.896	1.569
2	S-2	12.236	7.589	2.226	2.459	3.189	3.256	1.623
3	S-3	13.495	7.445	2.436	2.589	3.225	3.895	1.678
4	S-4	9.758	7.212	2.512	2.639	3.239	3.319	1.775
5	S-5	6.395	7.613	2.321	2.812	4.198	3.389	1.813
6	S-6	11.589	9.325	3.325	3.446	5.678	3.926	2.678
7	S-7	14.236	9.489	3.452	3.589	5.389	4.856	2.774
8	S-8	15.495	9.545	3.221	3.678	5.525	4.991	2.813
9	S-9	10.958	9.212	3.663	3.845	5.239	4.389	2.923
10	S-10	13.595	9.513	3.741	3.921	5.998	4.689	2.985
11	S-11	13.289	11.125	5.011	4.586	6.378	5.896	3.684
12	S-12	15.236	11.589	4.789	4.865	6.189	5.286	3.712
13	S-13	16.495	11.445	4.623	4.912	6.245	5.895	3.776
14	S-14	11.758	11.512	5.121	5.019	6.539	5.319	3.845
15	S-15	14.698	11.013	4.948	5.234	6.998	5.489	3.912

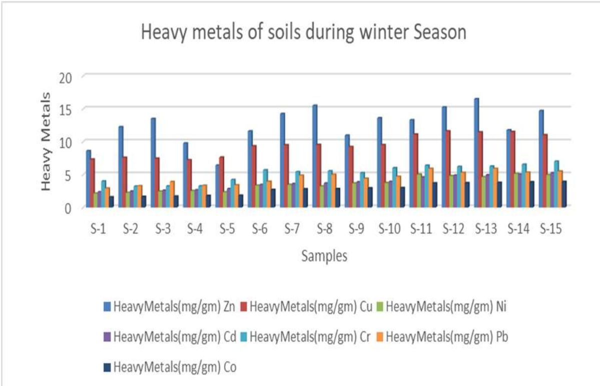

Figure 5: Heavy metals of soils during winter Season

c. Summer Season

Zn: The Zn concentration was 5.245mg/g, 6.408mg/g, 5.864mg/g, 6.271mg/g and 6.718mg/g in Site 1, 2, 3, 4 and 5 respectively.

Cu: The Cu concentration was 4.160mg/g, 4.049mg/g, 4.253mg/g, 4.306mg/g and 4.645mg/g in Site 1, 2, 3, 4 and 5 respectively.

Ni: The Ni concentration was 3.130mg/g, 3.436mg/g, 3.639mg/g, 3.546mg/g and 3.740 mg/g in Site 1, 2, 3, 4 and 5 respectively.

Cd: The Cd concentration was 3.667mg/g, 3.859mg/g, 3.658mg/g, 3.667mg/g and 3.570mg/g in Site 1, 2, 3, 4 and 5 respectively.

Cr: The Cr concentration was 4.297mg/g, 4.301mg/g, 4.285mg/g, 4.291mg/g and 4.303mg/g in Site 1, 2, 3, 4 and 5 respectively.

Pb: Pb concentration was 4.488mg/g, 4.396mg/g, 4.562mg/g, 4.406mg/g and 4.708mg/g in Site 1, 2, 3, 4 and 5 respectively.

Co: The Co concentration was 2.747mg/g, 2.764mg/g, 2.782mg/g, 2.759mg/g and 2.738 mg/g in Site 1, 2, 3, 4 and 5 respectively.

Table 12: Heavy metals of soils during summer Season

S. No.	Samples	Heavy Metals						
		Zn	Cu	Ni	Cd	Cr	Pb	Co
1	S-1	1.584	0.186	0.709	1.746	1.923	1.065	0.312
2	S-2	1.609	0.159	0.745	1.798	2.001	1.082	0.327
3	S-3	1.724	0.115	0.769	1.782	1.986	1.107	0.342
4	S-4	1.658	0.167	0.718	1.802	1.955	1.119	0.367
5	S-5	1.687	0.123	0.733	1.759	1.977	1.071	0.356
6	S-6	2.201	0.248	0.855	1.906	2.229	1.145	0.442
7	S-7	2.316	0.203	0.863	1.957	2.246	1.169	0.419
8	S-8	2.186	0.236	0.842	1.933	2.231	1.126	0.433
9	S-9	2.248	0.257	0.871	1.965	2.271	1.171	0.407

10	S-10	2.335	0.219	0.896	1.922	2.266	1.133	0.451
11	S-11	3.002	0.309	0.985	2.12	2.612	1.202	0.496
12	S-12	3.196	0.276	0.971	2.101	2.637	1.196	0.507
13	S-13	3.152	0.251	0.965	2.088	2.589	1.223	0.479
14	S-14	3.209	0.245	0.943	2.055	2.622	1.215	0.518
15	S-15	3.258	0.346	0.955	2.063	2.604	1.188	0.488

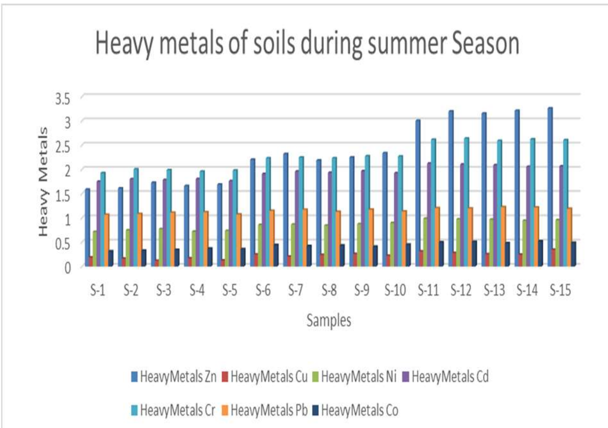

Figure 6: Heavy metals of soils during summer Season

HEAVY METAL ANALYSIS OF VEGETABLES

Heavy metal analysis from vegetable samples collected from agricultural fields of Sikar district was carried out from the soil material. Analysis was carried out by atomic absorption spectrophotometer (AAS).

Zn: Zn concentration of the soil samples collected from the fields of was 6.389mg/g, 9.236mg/g, 10.495mg/g, 7.758mg/g and 5.395mg/g in site 1, 2, 3, 4 and 5 respectively.

Cu: Cu concentration of the soil samples collected from the fields of Phaseolus mungo was 5.155mg/g, 5.189mg/g, 5.325mg/g, 5.202mg/g and 5.613mg/g in site 1, 2, 3, 4 and 5 respectively.

Ni: Ni concentration of the soil samples collected from the fields of Phaseolus mungo was 2.063mg/g, 2.126mg/g, 2.239mg/g, 2.409mg/g and 2.109mg/g in site 1, 2, 3, 4 and 5 respectively.

Cd: Cd concentration of the soil samples collected from the fields of Phaseolus mungo was 2.036mg/g, 2.236mg/g, 2.418mg/g, 2.523mg/g and 2.772mg/g in site 1, 2, 3, 4 and 5 respectively.

Cr: In the pre-flowering Cr concentration of the soil samples collected from the fields of Phaseolus mungo was 3.823mg/g, 3.229mg/g, 3.201mg/g, 3.224mg/g and 3.726mg/g in site 1, 2, 3, 4 and 5 respectively.

Pb: In the pre-flowering Pb concentration of the soil samples collected from the fields of Phaseolus mungo was 2.706mg/g, 3.202mg/g, 3.693mg/g, 3.301mg/g and 3.256mg/g in site 1, 2, 3, 4 and 5 respectively.

Co:- In the pre-flowering Co concentration of the soil samples collected from the fields of Phaseolus mungo was 1.569mg/g, 1.601mg/g, 1.612mg/g, 1.709 mg/g and 1.798 mg/g in site 1, 2, 3, 4 and 5 respectively.Table 13: Heavy metals of Vegetables

S. No.	Sites	Heavy Metals(mg/gm)						
		Zn	Cu	Ni	Cd	Cr	Pb	Co
1	S-1	6.389	5.155	2.063	2.036	3.823	2.706	1.569
2	S-2	9.236	5.189	2.126	2.236	3.229	3.202	1.601
3	S-3	10.495	5.325	2.239	2.418	3.201	3.693	1.612
4	S-4	7.758	5.202	2.409	2.523	3.224	3.301	1.709
5	S-5	5.395	5.613	2.109	2.772	3.726	3.256	1.798
6	S-6	11.526	7.325	3.203	3.056	5.261	3.712	2.502
7	S-7	13.239	7.489	3.228	3.236	5.128	4.023	2.561
8	S-8	13.625	7.545	3.209	3.562	5.346	4.198	2.712
9	S-9	10.881	7.212	3.512	3.627	5.329	4.332	2.806
10	S-10	11.496	7.363	3.662	3.824	5.821	4.541	2.903
11	S-11	13.281	9.105	4.023	4.056	6.028	5.235	3.459
12	S-12	15.212	9.589	4.381	4.129	6.112	5.292	3.623
13	S-13	16.481	9.445	4.852	4.887	6.205	5.306	3.369
14	S-14	11.652	9.512	5.096	5.003	6.446	5.369	3.562
15	S-15	14.425	9.013	4.812	5.139	6.825	5.402	3.259

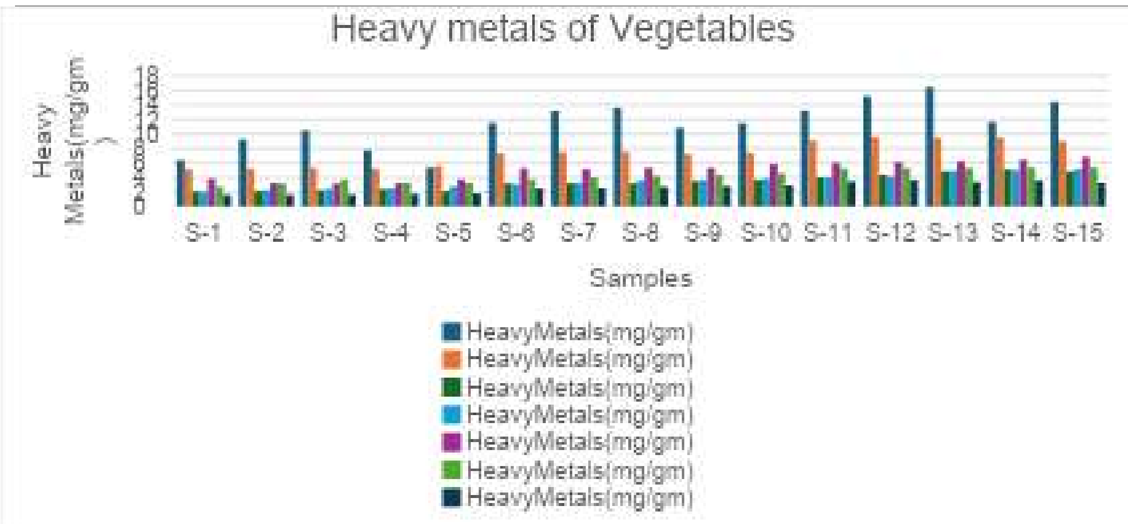

Figure 7: Heavy metals of Vegetables

DESCRIPTIVE STATISTICS

Below are the summary statistics (mean and standard deviation) for the heavy metal concentrations in soil and vegetables based on the irrigation type:

Irrigation Type	Soil Pb (mean ± SD)	Soil Cd (mean ± SD)	Soil Hg (mean ± SD)	Soil As (mean ± SD)	Veg Pb (mean ± SD)	Veg Cd (mean ± SD)	Veg Hg (mean ± SD)	Veg As (mean ± SD)
Sewage Effluent	47.05 ± 2.62	2.90 ± 0.14	0.17 ± 0.02	10.65 ± 0.49	31.65 ± 2.19	1.50 ± 0.14	0.09 ± 0.01	5.60 ± 0.57

Conventional Irrigation	14.05 ± 1.65	0.60 ± 0.14	0.03 ± 0.01	3.30 ± 0.28	9.10 ± 1.27	0.35 ± 0.07	0.015 ± 0.005	2.20 ± 0.28
Mixed Irrigation	25.60 ± NA	1.20 ± NA	0.08 ± NA	6.40 ± NA	18.50 ± NA	0.60 ± NA	0.04 ± NA	3.70 ± NA

III. Conclusion

In conclusion, the use of sewage effluent for irrigation poses significant risks of soil contamination due to the elevated concentrations of heavy metals such as lead, cadmium, mercury, and arsenic. Our data analysis has revealed substantial differences in metal concentrations between soils irrigated with sewage effluent and those irrigated with conventional groundwater, highlighting the need for effective treatment and monitoring of effluent before its use in agriculture. The findings of our study align with existing literature, which emphasizes the long-term environmental and health implications of heavy metal accumulation in soils. To mitigate these risks, it is imperative to implement stringent regulations, employ advanced treatment technologies, and raise awareness among farmers about the importance of using treated effluent. By adopting a comprehensive approach to managing sewage effluent irrigation, we can safeguard soil health, protect food safety, and ensure the sustainability of agricultural practices in the face of growing water scarcity 9.10 mg/kg. Similarly, cadmium levels were significantly higher in vegetables from sewage effluent-irrigated areas, with a mean concentration of 1.50 mg/kg compared to just 0.35 mg/kg in vegetables from conventional irrigation areas. These findings align with studies conducted by Dickin et al. (2016) and Berhanu et al. (2022), which also reported that wastewater irrigation leads to significant contamination of crops with heavy metals, thereby posing substantial health risks to consumers.

The elevated levels of heavy metals in vegetables are of particular concern due to the potential for bioaccumulation and biomagnification through the food chain. Heavy metals such as lead and cadmium are not readily excreted by the human body and can accumulate in various organs, leading to toxic effects. Lead exposure, even at low levels, can result in neurological impairments, particularly in children, affecting their cognitive development and academic performance. Chronic exposure to cadmium can cause kidney damage, skeletal demineralization, and an increased risk of cancer. These health risks underscore the importance of addressing the contamination of vegetables grown in sewage effluent-irrigated areas.

The contamination of vegetables with heavy metals is influenced by several factors, including the type and concentration of metals in the sewage effluent, the properties of the soil, and the specific characteristics of the vegetable species. Heavy metals can be taken up by plant roots from the soil and translocated to various parts of the plant, including the edible portions. The extent of metal uptake and accumulation can vary among different vegetable species, with leafy vegetables typically showing higher levels of accumulation compared to root and fruit vegetables. This variability highlights the need for targeted monitoring and intervention strategies to mitigate the risks of heavy metal contamination in different types of vegetables.

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ISSN: 2096-3246
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