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Integrated Evaluation of Chemical Properties and Heavy Metal Levels in Agricultural Soils for Sustainable Environmental Management

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Abstract

Agricultural soil health is crucial for sustainable food production and environmental sustainability. This study integrates the evaluation of chemical properties and heavy metal levels in agricultural soils to assess their impact on soil health and environmental sustainability. Soil samples from [location/region] were analyzed for pH, electrical conductivity, nutrient levels, and heavy metals (Ni, Pb, Cd, Cr). Results showed significant variations in chemical properties and heavy metal concentrations, exceeding permissible limits in some cases. The study identifies correlations between chemical properties and heavy metal levels, highlighting potential risks to soil biota, human health, and the environment. The findings emphasize the need for sustainable soil management practices, including efficient irrigation systems, organic amendments, and regular monitoring. This research contributes to the development of evidence-based guidelines for maintaining soil fertility, mitigating heavy metal pollution, and ensuring environmental sustainability in agricultural ecosystems.

Keywords: Agricultural soil health, Chemical properties, Heavy metal pollution, Environmental sustainability

I. INTRODUCTION

Water availability is a significant concern in many agricultural areas, traditional sources for irrigation are increasingly strained due to rising demand and climate change. Scarcity poses serious challenges for agriculture, depends on reliable water supplies for crop growth and productivity. In response to these challenges, treated wastewater(TWW) has emerged as a valuable alternative. By recycling and reusing treated municipal and industrial effluents, TWW offers a potential solution to mitigate water shortages. TWW often contains essential nutrients such as nitrogen, phosphorus, and potassium, enrich soil fertility and support plant growth. The addition of these nutrients can reduce the need for synthetic fertilizers, contributing to more sustainable agricultural practices. Soil pollution due to heavy metal contamination has emerged as a critical environmental concern, posing significant risks to agricultural productivity, ecosystem health, and human well-being [1]. The increasing use of treated effluent for irrigation and industrial activities have led to elevated levels of heavy metals in agricultural soils [2]. Heavy metals such as nickel (Ni), lead (Pb), cadmium (Cd), and chromium (Cr) can accumulate in soils, potentially harming soil biota, contaminating groundwater, and entering the food chain [3]. Soil chemical properties, including pH, electrical conductivity (EC), and nutrient levels, play a crucial role in determining heavy metal availability and mobility [4]. Understanding the relationships between soil chemical properties and heavy metal concentrations is essential for developing effective management strategies to mitigate these risks [5]. In recent years, numerous studies have investigated heavy metal contamination in agricultural soils, highlighting the need for sustainable soil management practices [6]. Guidelines and directives from international organizations and governments emphasize the importance of monitoring and mitigating heavy metal pollution in soils [7] [8]. However, there is a lack of comprehensive research integrating chemical properties and heavy metal levels in agricultural soils, particularly in [Region/Location]. This study aims to bridge this knowledge gap by investigating the chemical properties (pH, EC, nutrient levels) and heavy metal levels (Ni, Pb, Cd, Cr) in agricultural soils in [Region/Location]. The findings of this study will provide valuable insights for policymakers, farmers, and environmental managers to develop evidence-based strategies for maintaining soil fertility, mitigating heavy metal pollution, and ensuring environmental sustainability [9] [10].

II.METHODOLOGY

Study Area Description

Davanagere, a city in Karnataka, is undergoing transformation under the Central government's Smart City initiative, with a population of approximately 530,000 residents as per the 2021 census.Municipal STP are made to handle garbage that originates in cities. One STP, with a 20MLD capacity, is situated in Shivanagar, Davanagere. This STP releases its treated wastewater into a canal that runs beside the villages of Doddabudihal, Chikkabudihal, and others before joining the Thunga Bhadra river. Doddabudihal, which is too close to the STP, is chosen as site 1 for sampling and analysis. Slightly away from the STP, Chikkabudihal is regarded as site 2, while B. Kalpanahalli is regarded as site 3.

Fig 1.Study Area

Sample Collection

The V approach was used to gather samples from an agricultural area. A circle was formed by thoroughly mixing about 10 samples, taken in a zigzag pattern from each location. The 2 opposing portions and 4 equal divisions from this circle were then thrown away. Once more, the last 2 pieces fused to form a circle. Next, the diagonal 2 portions were removed and again divided into 4 equal sections once more. From the remaining soilweighed around 1/2kg was taken.

Method of Soil Sample Analysis

Soil samples from Doddabhudihal, Chikkabudhihal and B.Kalpanhalli locations affected by treated wastewater (TWW) were analyzed to assess its impact on soil properties. The analysis included evaluations of physical properties such as soil texture, bulk density, and moisture content. Chemical properties like nutrient levels, soil pH, and electrical conductivity were also measured, along with the concentration of heavy metals such as lead, cadmium, and chromium.

Table.1 Methods used for Analysis

Chemical Properties	Methods
pH	Electrochemical method
Electrical Conductivity	
Available Nitrogen	Kjeldahl Method
Available Phosphorous	Osla’s Method
Available Potassium	FES
Available Organic Carbon	Wet Digestion Method
Available Iron	DTPA
Available Magnesium	
Heavy metals	AAS

III. Result and Discussion

pH values range from 6.4 to 8.35, indicating slightly acidic to moderately alkaline soils. Soils with higher pH influenced by the accumulation of calcium (Ca) and magnesium (Mg), which are common in alkaline soils. Lower pH values due to organic matter decomposition, especially in areas where organic carbon (OC) is higher. Electrical conductivity (EC) is generally low (ranging from 0.02 to 0.35 dS/m), suggesting minimal salinity issues, which is positive for plant growth. However, the slightly elevated EC in certain areas (e.g., 0.35) could point to localized salt accumulation, due to poor drainage or the use of saline irrigation water.Organic carbon (OC) varies from 0.54% to 1.36%, reflecting the organic matter content in the soil. Higher OC values promote nutrient retention and soil structure, contributing to better fertility. Nitrogen (N) levels fluctuate from 196.78 to 285.15 kg/ha, with the lower values potentially indicative of poor organic matter or insufficient nitrogen-fixing processes, while higher values due to adequate organic inputs or fertilization.Phosphorus (P) levels, ranging from 9.416 to 34.702 kg/ha, are variable. Phosphorus availability limited in high-pH soils, as it tends to bind with calcium, making it less available to plants. The soils with higher phosphorus (above 30 kg/ha) might reflect recent fertilization or optimal soil conditions for phosphorus retention.Potassium (K) concentrations (94.16 to 347.02 kg/ha) are generally moderate to high, with higher values supporting crop growth, especially in soils with adequate organic matter or clay content, which retain potassium. The lower potassium levels might reflect a depletion due to crop uptake or leaching in sandy soils.Calcium (Ca) content, ranging from 1,266.25 to 4,312.5 ppm, indicates variability in the base saturation of the soil, where higher calcium values are typical in alkaline soils with more significant lime content. Magnesium (Mg) levels (ranging from 167.5 to 613.75 ppm) follow a similar trend, with higher levels in alkaline conditions, possibly contributing to the elevated pH.Iron (Fe) levels (2.63 to 26.12 ppm) are generally adequate, but the lower iron concentrations in higher-pH soils could be due to iron being less available in alkaline conditions, leading to potential deficiencies for iron-sensitive crops.Manganese (Mn) levels (2.5 to 11.98 ppm) are generally sufficient, but higher concentrations can be toxic, especially in acidic soils. However, the levels reported are within a reasonable range for most crops, though areas with lower Mn may reflect a deficiency linked to high soil pH, which reduces Mn availability.

Table 2. Analysis of Chemical Properties

S.No	**pH**	**EC**	**OC**	**N (kg/ha)**	**P (kg/ha)**	**K (kg/ha)**	**Ca (ppm)**	**Mg (ppm)**	**Fe (ppm)**	**Mn (ppm)**
1	6.4	0.24	0.81	230.2	23.381	233.81	2930.62	456.87	17.34	2.5
2	7.47	0.12	1.36	198.4	9.416	94.16	2917.5	613.75	13.49	3.49
3	7.46	0.1	1.09	245.22	9.522	95.22	2674.37	545.62	12.66	8.07
4	7.94	0.08	1.09	231.72	13.172	131.72	2055.62	560	2.63	4.98
5	7.5	0.15	1.09	285.15	18.515	185.15	1266.25	478.12	15.74	6.26
6	7.35	0.07	0.54	264.51	16.451	164.51	3590.4	399.37	17.65	2.9
7	8.35	0.14	1.09	196.78	19.678	196.78	3369.37	583.75	19.35	3.04
8	7.77	0.35	1.36	247.02	34.702	347.02	4058.12	536.25	3.29	3.55
9	7.74	0.02	1.09	226.18	28.618	286.18	2487.5	550.62	2.84	7.96
10	6.98	0.08	1.09	212.63	31.263	312.63	2891.87	474.02	6.44	5.13

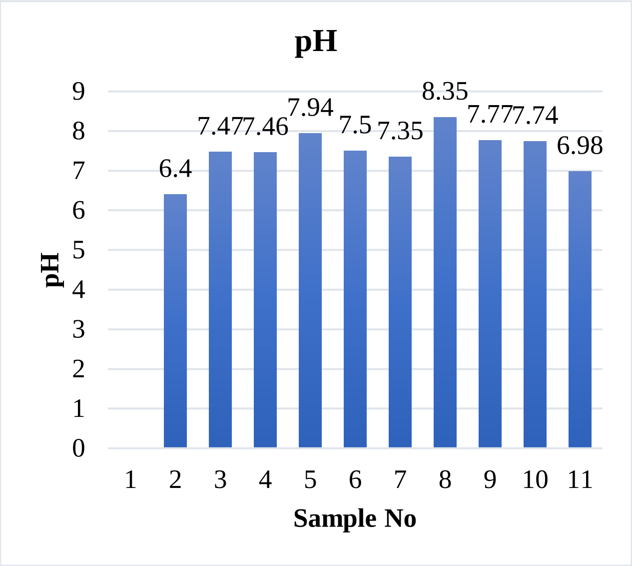


Fig.2 Analysis of pH

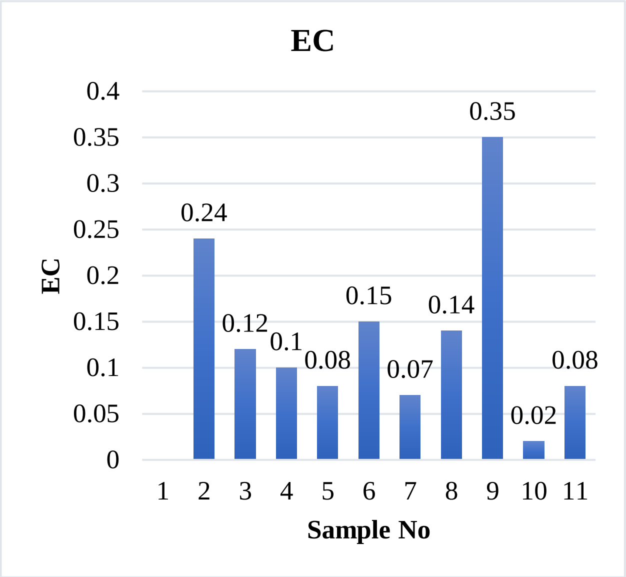


Fig.3 Analysis of EC

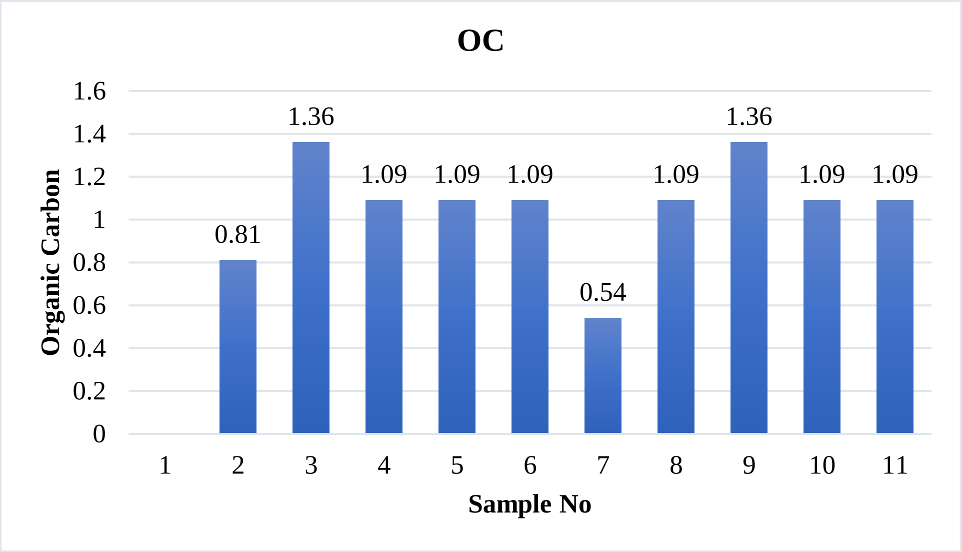
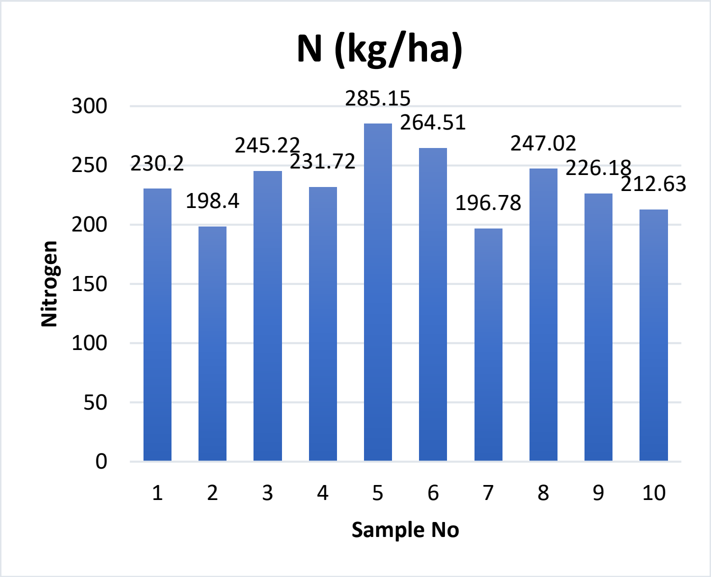


Fig.4 Analysis of Organic Carbon



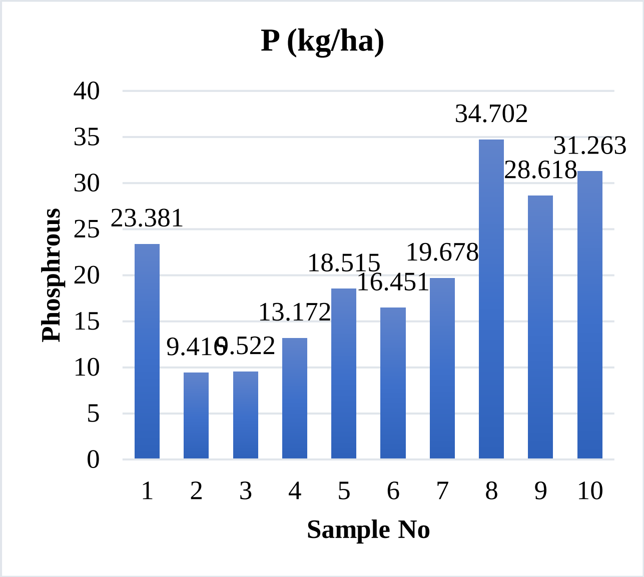
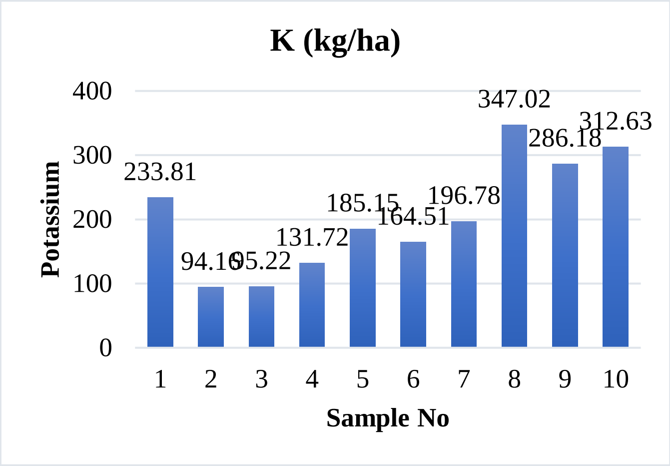


Fig.5 Analysis of Nitrogen

Fig.6 Analysis of Phosphorus



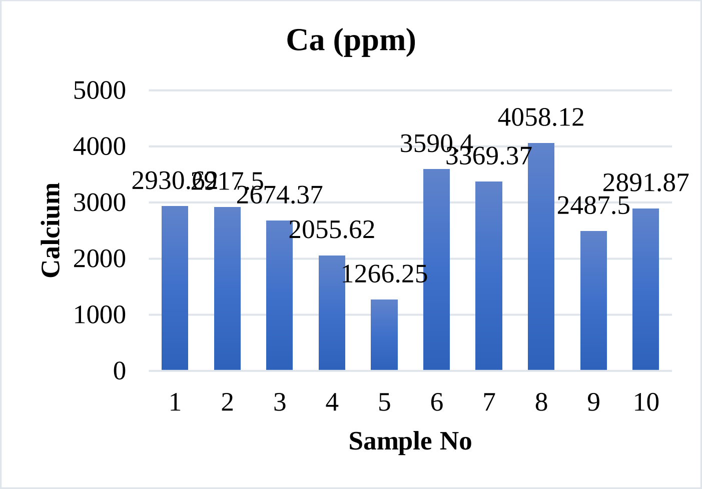


Fig.7 Analysis of Potassium

Fig.8 Analysis of Calcium

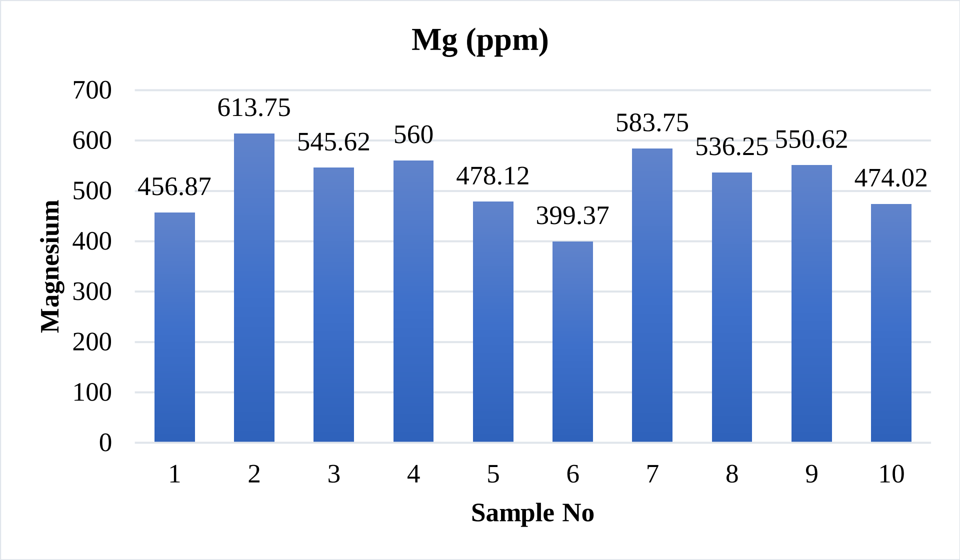
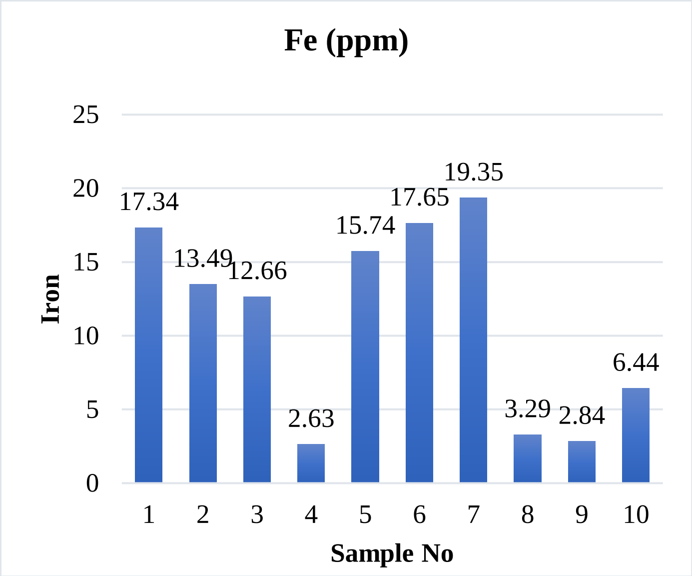


Fig.9Analysis of Magnesium



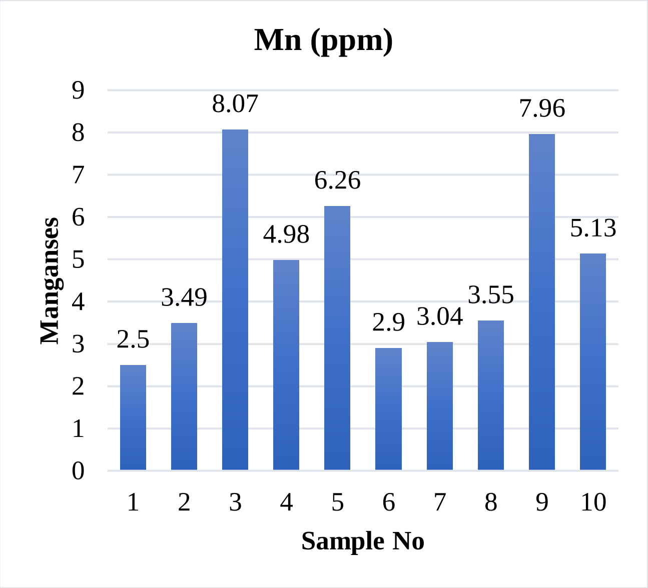


Fig.10 Analysis of Iron

Fig.11 Analysis of Manganese

Heavy Metals

Table 3. Analysis of Heavy metals

Sample No.	Ni(mg/kg)	Pb(mg/kg)	Cd(mg/kg)	Cr(mg/kg)
1	42	129	2	100
2	62	111	4	100
3	46	126	2	100
4	44	109	2	100
5	62	125	6	100
6	56	132	4	100
7	62	168	2	100
8	42	172	2	100
9	78	102	4	100
10	45	156	2	100

The soil samples exhibit varying levels of heavy metals, with nickel (Ni) values ranging from 42-78 mg/kg, lead (Pb) values spanning 102-172 mg/kg, cadmium (Cd) levels between 2-6 mg/kg, and chromium (Cr) values consistently at 100 mg/kg. High Ni and Pb values, exceeding permissible limits, indicate significant contamination, potentially from treated effluent irrigation. Cd levels, however, remain below permissible limits, suggesting minimal impact. Cr values, while equal to the permissible limit, warrant attention. Proximity to industrial or urban areas, soil pH, and organic matter content may contribute to high values. Conversely, natural attenuation processes and soil characteristics may explain lower values. These findings have environmental implications, as soil contamination impact plant growth, soil biota, and human health, while also potentially leaching into groundwater and affecting aquatic ecosystems.Inadequate wastewater treatment, poor irrigation management, and lack of regulatory enforcement exacerbate heavy metal contamination in soils, posing risks to environmental and human health.

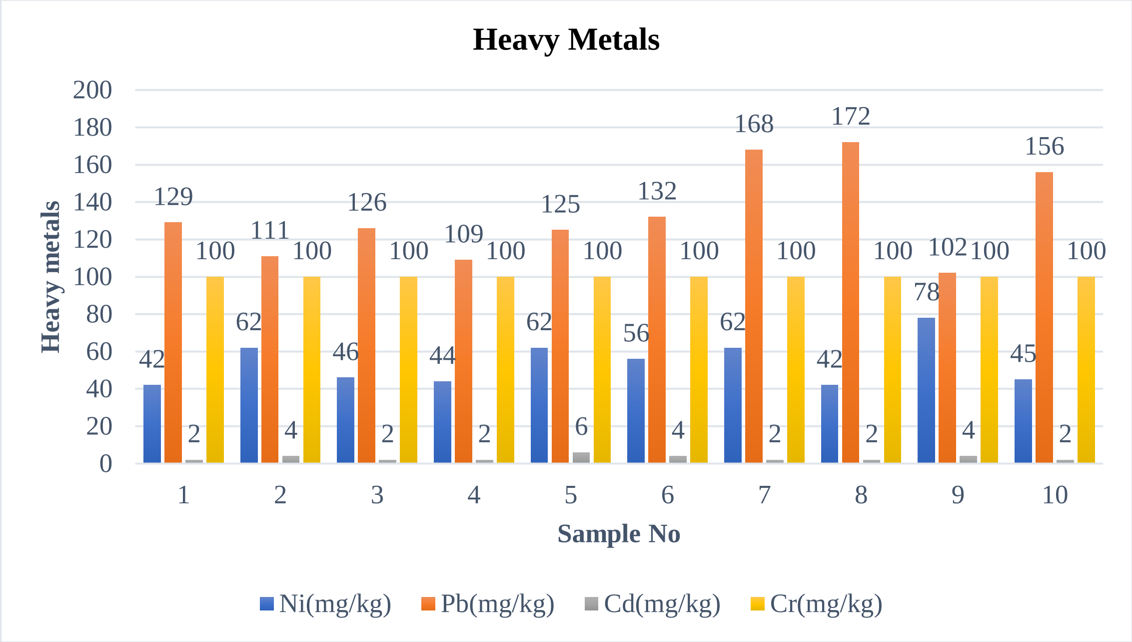


Fig.12 Analysis of Heavy metals

Conclusion

The soil samples from DoddaBhudihal, ChikkaBhudihal, and B.Kalpanahalli exhibit varying properties, with neutral to slightly alkaline pH, high electrical conductivity, and moderate to high levels of nitrogen, phosphorus, and potassium. Heavy metal analysis reveals high levels of nickel and lead, exceeding permissible limits, while cadmium levels are within limits, and chromium values are at the threshold. The use of treated effluent for irrigation, proximity to industrial areas, and inadequate wastewater treatment likely contribute to contamination. These findings highlight the need for effective wastewater management, regulatory enforcement, alternative irrigation sources, soil remediation, and public awareness to mitigate heavy metal contamination, ensure environmental sustainability, and protect human health, ultimately guiding agricultural management and policy decisions to optimize soil fertility and crop growth while minimizing environmental risks

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