Status ~~Assessment of~~ of Heavy Metals ~~Status~~ in Irrigation water in the Central Narmada Valley Zone of Madhya Pradesh, India ~~Using GIS~~

ABSTRACT

Water quality deteriorating due to the growing global population. In the present study, a total of 104 water samples were collected from Central Narmada Valley zone Madhya Pradesh and analysed using ICP-MS/MS in the laboratory the results showed that the mean concentrations of 3.49 μgL^{-1}, 4.203 μgL^{-1},40.43 mgL^{-1}, 0.24 μgL^{-1}, 10.42 μgL^{-1}, 0.58 μgL^{-1}, 4.81 μgL^{-1}, 0.344 μgL^{-1},0.019 μgL^{-1}, 1.58 μgL^{-1}, and 1.97 μgL^{-1}, of Cu, Zn, Mn, Fe, Cr, Co, Ni, Cd , Hg , Pb and As respectively. The concentrations of these metals varied across the districts, with substantial fluctuations indicated by high coefficients of variation (CV %). The Cu and Zn showed high CV%, in Narsinghpur (120.51%) and Narmadapuram (164.51%), suggesting irregular distribution. Mn status showed considerable variation, with extreme values in Narmadapuram, while Fe concentrations were relatively low, Although the concentrations of Fe, Cr and As occasionally exceeded lower thresholds, all metals remained within the permissible limits set by the WHO. The highest CV% was observed for Hg in Harda, indicating considerable variability in status. Overall, the findings, ~~suggested~~ continuous monitoring is recommended to ensure the safety of irrigation water.

Keyword: Heavy Metals, Irrigation Water, GIS, GPS. Arsenic, Mercury

INTRODUCTION

Water is a vital resource and about 2.5% of surface fresh water is used for agriculture, domestic activities, industry, and supporting aquatic life. Declining water quality impacts agricultural use and consumption by humans and animals. Heavy metal contamination in irrigation water poses serious risks to both environmental sustainability and public health. The study area is extensively cultivated ~~of~~ with wheat~~.~~, soybean and mungbean whose irrigation water playing a critical role in supporting local farming practices. However, over the years, the quality of irrigation water has been compromised due to the increasing presence of heavy metals.

As these metals accumulate in the soil, they can be taken up by crops, ultimately entering the food chain and affecting the health of local communities. Furthermore, the persistent and non-biodegradable nature of heavy metals exacerbates the problem, making it a long-term challenge for the region. Understanding the trends of heavy ~~metals is~~metals is vital for developing effective strategies for water management and pollution mitigation in Flouchi et al., 2021).

. presence of heavy metals in water degrades its quality. Various methods are available for detecting heavy metal contamination in water, including inductively coupled plasma mass spectrometry (ICP-MS/MS).

Heavy metals are non-biodegradable and therefore persist for a long time in aquatic and terrestrial environments. They can be transported from soil to groundwater or taken up by plants (Jamali et al., 2009). They can enter the human body through the food chain, accumulating over time and leading to various health problems, including kidney disease, hormonal imbalances, hair loss, cardiovascular issues, neurological and

Commented [Dr-APR1]: Give reference

endocrine disorders, cancer, and respiratory and digestive problems. Furthermore, the distribution of heavy metals in aquatic ecosystems can disrupt the biotic community, influencing biogeochemical processes and forming harmful complexes with organic matter. Long-term studies have shown that using contaminated water for irrigation can elevate the risk of heavy metal accumulation in soil and crops, ultimately threatening food safety and public health. Assessment of heavy metals in water is therefore crucial for safeguarding human health.

Commented [Dr-APR2]: Give reference to these studies

2. MATERIAL AND METHODS

2.1 Study area for water sampling

The study focuses on the Central Narmada Valley zone, which includes the districts of Narsinghpur, Hoshangabad, Harda, and parts of Sehore and Raisen in Madhya Pradesh (Fig. 1). This region lies between latitudes 22° and 23° and longitudes 76° and 79°. The area is predominantly composed of irrigated land, utilizing canals, tubewells, and wells, with deep black, sandy loam, and medium black soils. It receives annual rainfall between 1200 and 1600 mm, and the primary cropping system is Sugarcane based in Narsinghpur and wheat-soybean-summer mungbean.

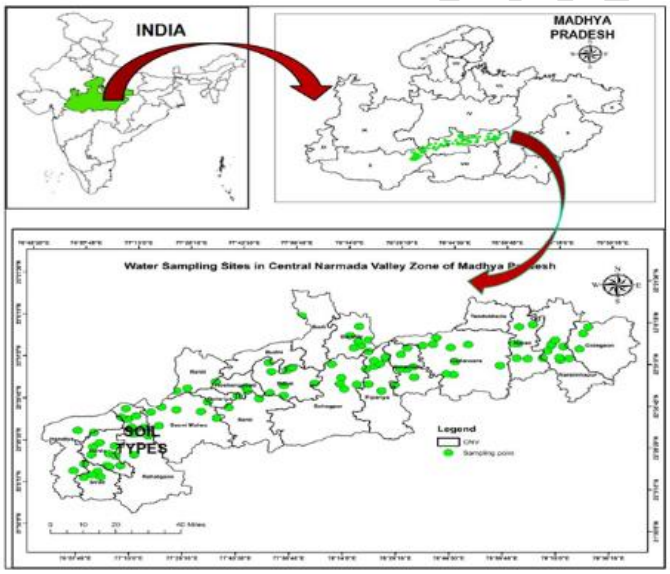


Fig. 1 Study area of sampling sites

2.2 Sample collection and analysis

Water samples were collected in 500 ml PVC bottles, carefully labeled, and thoroughly cleaned by washing with distilled water before collection. In the Central Narmada Valley Zone, a total of 104 water samples were gathered from different districts: 28 from Narsinghpur, 42 from Narmadapura, 26 from Harda, 6 from

partially Bareli and 2 from partially Raheti. These samples were collected from a variety of sources, including rivers, canals, wells, ponds, and tube wells, to examine the chemical quality of water in the region. Various heavy ~~matel~~metals, including arsenic (As), chromium (Cr), cobalt (Co), copper (Cu), cadmium (Cd), mercury (Hg), nickel (Ni), lead (Pb), zinc (Zn) and iron (Fe) concentrations, were measured to assess the quality of irrigation water. In order to determine the metal content, the collected sample was filtered and placed 5 ml in test tube ~~than~~ and treated with 0.25 ml of nitric acid and 0.15 ml hydrochloric acid (Trace metal grade). Heavy metals content in irrigation water samples were determined by Inductively Coupled Plasma - Mass Spectrometry (ICP-MS) and standards curve (Fig .2).

Commented [Dr-APR3]: Explain what is meant by "partially"

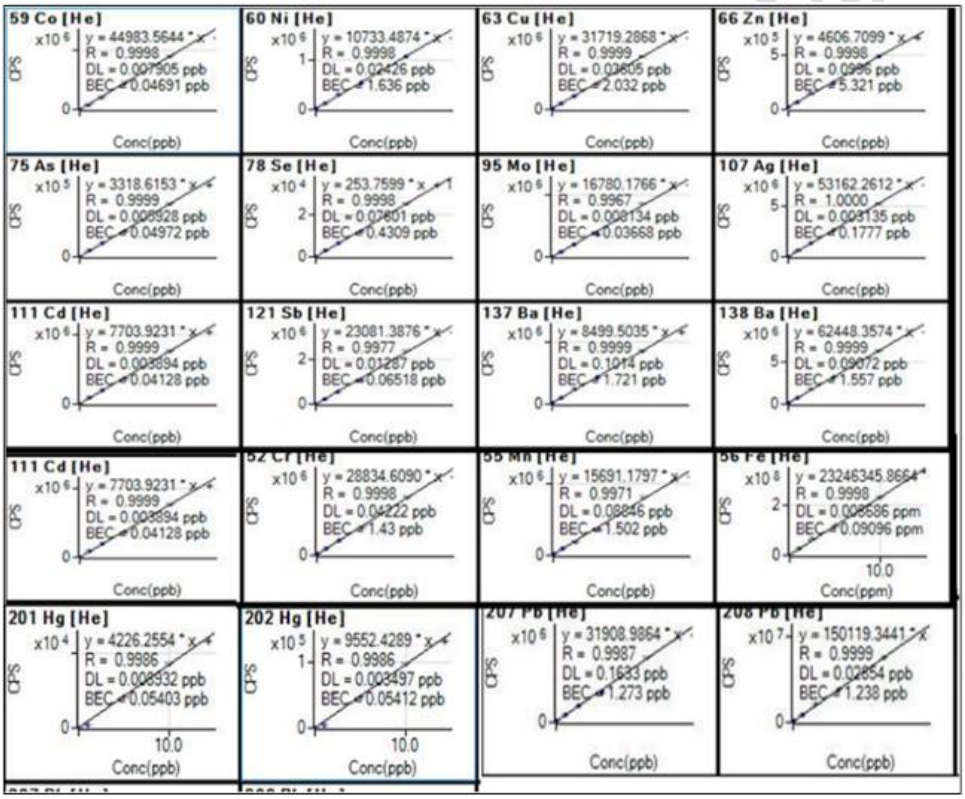


Fig. 2 Standard curve for Heavy metal content analysis using ICP-MS

2.3 Statically methods

Commented [Dr-APR4]: Statistical???

The minimum, maximum, mean and coefficient of variation value. The coefficient of variation (CV) can be used to describe the dispersion degree of each sample, CV< 10% belongs to weak variation, 10%_ CV_ 100% belongs to moderate variation, and CV> 100% belongs to strong variation (Zhou et al. 2016).

3. RESULTS AND DISCUSSION

3.1 Copper (Cu)

The status of Cu in the water samples is presented in Table 1, it ~~was~~ ranged from 0.30 to 41.94, 0.04 to 22.41, 0.04 to 0.19, 0.30 to 13.46 and 0.08 to 0.17 μgL^{-1} with a mean value of 6.92, 3.29, 0.08, 4.75 and 0.12 μgL^{-1} in Narsinghpur, Narmdapuram, Harda, Partly Raisen (Bareli) and Partly Sehore (Raheti)district, respectively. The CV of 120.51, 164.51, 39.59, 109.19 and 50.69%, respectively. Overall ranged from 0.04μgL^{-1} (Narmdapura) to 41.94 μgL^{-1} (Narsinghpur) with a mean value 3.49μgL^{-1} (The lowest in Narmdapura and The highest in Narsinghpur). High coefficients of variation (CV %) for Cu, particularly in Narsingpur (120.51%) and Narmdapura (164.51%), suggest irregular patterns of contamination. In overall all the samples fall under the permissible limit of 2000 μgL^{-1}according to WHO (2017).

3.2 Zinc (Zn)

The status of Zn in the water samples is presented in Table 1, it ~~was~~ ranged from 0.090 to 24.242, 0.004 to 57.864, 0.009 to 0.111, 0.25 to 29.15 and 0.012 to 0.031 ugL^{-1} with a mean value and CV of 5.18, 5.269, 0.032, 11.622 and 0.022 ugL^{-1} and 96.29, 38.18, 139.18, 111.53 and 159.86 % in Narsinghpur, Narmdapuram, Harda, Partly Raisen (~~bareli~~Bareli) and Partly Sehore (Raheti) district, respectively. Over all, it was ranged from 0.004 μgL^{-1} (Narmdapuram) to 57.86 μgL^{-1} (Narmdapura) with a mean value 4.20 μgL^{-1} (The lowest in Harda and The highest in Partly Bareli).The highest CV% was found in Partly Raheti (159.86%), indicating significant fluctuations in Zn contamination. The obtained values were under the permissible levels of 1000 μgL^{-1}according to WHO (2017).

3.3 Manganese (Mn)

The status of Cu in the water samples is presented in Table 1, it ~~was~~ ranged from 1.74 to 380.06, 0.02 to 752.57, 0.01 to 5.87, 3.99 to 210.91 and 0.05 to 0.07μgL^{-1} with a mean value and CV 55.40, 54.95, 0.44, 55.64 and 0.06μgL^{-1} and 158.24, 257.24, 302.11, 143.88 and 32.05% in Narsinghpur, Narmdapuram, Harda, Partly Raisen (bareli) and Partly Sehore (Raheti) district, respectively. Mn concentration showed a wide range, from 0.01 μgL^{-1} (Harda) to 752.57 μgL^{-1} (Narmdapura) with mean value 40.43μgL^{-1} (The lowest in Partly Sehore and The highest in Partly Raisen). High CV% values, such as 302.11% in Harda, suggest sporadic pollution or localized sources of contamination. The mean concentration of Mn in tested water is permissible limit of 100 μgL^{-1}according to WHO (2017).

3.4 Iron (Fe)

The status of Fe in the water samples is presented in Table 1, it ~~was~~ ranged from 0.05 to 1.50, 0.01 to 2.44, 0.01 to 0.27, 0.04 to 2.57 and 0.01 to 0.03 ugL^{-1} with a mean value and The CV 0.34, 0.22, 0.04, 0.90 and 0.02 ugL^{-1} and 97.95, 53.28, 57.17, 89.91 and 141.42% in Narsinghpur, Narmdapuram, Harda, Partly Raisen (Bareli) and Partly Sehore (Raheti) district, respectively. Over all, it was ranged from 0.01 to 2.57 ugL^{-1} with a mean value 0.24ugL^{-1}. The CV% for Fe ranged from 53.28% in Narmadapuram to 141.42% in Partly Raheti, indicating significant variability in the metals presence. The obtained values were under the permissible levels of 300 μgL^{-1}according to WHO (2017).

3.5 Chromium (Cr)

The Cr concentration in the water samples is presented in Table 1, it ~~was~~ ranged from 0.916 to 231.82, 0.010 to 133.089, 0.001 to 0.090, 3.923 to 39.681 and 0.012 to 0.013 μgL^{-1} with a mean value and The CV 20.58, 10.176, 0.013, 13.273 and 0.013 μgL^{-1} and 47.986, 41.743, 79.816, 93.287 and 1767.767 % in Narsinghpur, Narmdapuram, Harda, Partly Raisen (bareli) and Partly Sehore (Raheti) district, respectively. Over all from 0.001 μgL^{-1} (Harda) to 231.823 µgL-1 (Narsinghpur) with a mean value 37.152 μgL^{-1} (The lowest in Harda and Partly Rahati and The highest in Narsinghpur). The mean concentration of Cr in tested water is below than permissible limit of 50 μgL^{-1} according to WHO (2017).

3.6 Cobalt (Co)

The Co concentration in the water sample is presented in Table 1, it ~~was~~ ranged from 0.15 to 3.48, 0.06 to 3.94, 0.01 to 1.42, 0.18 to 1.12 and 0.20 to 0.24 μgL^{-1} with a mean value of 0.79, 0.67, 0.29, 0.48 and 0.22μgL^{-1} in Narsinghpur, Narmdapuram, Harda, Partly Raisen (bareli) and Partly Sehore (Raheti) district, respectively. Over all, it was ranged from 0.01 μgL^{-1} (Harda) to 3.94μgL^{-1}(Narmdapura) with mean value 0.58 μgL^{-1}(The lowest in Partly Rahati and The highest in Narsingpur). The CV% for Co ranged from 11.62% in Partly Raheti to 114.09 % in Harda. The mean concentration of cobalt in tested water is below permissible limit of 50 μgL^{-1}according to WHO (2017).

3.7 Nickel (Ni)

The Ni concentration in the water samples is presented in Table 1, it ~~was~~ range from 1.09 to 18.58, 0.83 to 49.31, 0.29 to 5.45, 1.19 to 10.43 and 2.49 to 15.56 μgL^{-1} with a mean value 6.36, 5.40, 1.94, 4.52 and 9.03 μgL^{-1} in Narsinghpur, Narmdapuram, Harda, Partly Raisen (Bareli) and Partly Sehore (Raheti) district, respectively. Over all, it was ranged from 0.29 μgL^{-1}(Harda) to 49.31 µgL-1 (Narmdapura) with amean value

4.81ugL^{-1}.The highest CV% (159.33%) was found in Narmdapura, reflecting significant variability in contamination levels. The obtained values were under the permissible levels of 70 µgL^{-1} according to WHO (2017).

3.8 Cadmium (Cd)

The Cd concentration in the water samples is presented in Table 1, it ~~was~~ ranged from 0.002 to 0.671, 0.002 to 30.351, 0.002 to 0.092, 0.005 to 0.167 and 0.009 to 0.012 ugL^{-1} with a mean value and The CV 0.087, 0.77, 0.025, 0.057 and 0.011 ugL^{-1} and 61.999, 16.455, 112.754, 91.339 and 494.975 % in Narsinghpur, Narmdapuram, Harda, Partly Raisen (bareli) and Partly Sehore (Raheti) district, respectively. Overall, it was ranged from 0.002 ugL^{-1} (several locations) to 30.351 ugL^{-1} (Narmdapura) with mean value and CV 0.344 µgL^{-1} (The lowest in Partly Raheti and The highest in Narmadapuram) and 11.569%. In overall all the samples fall under the permissible limit of 10 µgL^{-1} according to WHO (2017).

3.9 Mercury (Hg)

The Hg concentration in the water samples is presented in Table 1, it ~~was~~ ranged from 0.001 to 0.254, 0.001 to 0.357, 0.001 to 0.004, 0.001 to 0.166 and 0.001 to 0.004 ugL^{-1} with a mean value 0.024, 0.024, 0.002, 0.029 and 0.003 ugL^{-1} in Narsinghpur, Narmdapuram, Harda, Partly Raisen (Bareli) and Partly Sehore (Raheti) district, respectively. Over all, it ranged from 0.001 to 0.357 ugL^{-1} with a mean value 0.019 ugL^{-1}. The CV% for mercury was notably high (213.023 %) in Harda. Indicating all the sample fall under the permissible limit according to WHO (2017).

3.10 Lead (Pb)

The Pb concentration in the water samples is presented in Table 1, it ~~was~~ ranged from 0.34 to 24.05, 0.01 to 6.51, 0.01 to 1.36, 0.74 to 13.46 and 0.02 to 0.11 µgL^{-1} with a mean value and The CV 2.78, 1.17, 0.36, 4.67 and 0.06 µgL^{-1} and 63.64, 73.80, 89.21, 90.25, and 92.36% in Narsinghpur, Narmdapuram, Harda, Partly Raisen (Bareli) and Partly Sehore (Raheti) district, respectively. Over all, it ranged from 0.01 to 24.05 µgL^{-1} with a mean value 1.58 ugL^{-1}. The CV% for Pb across all locations was 53.51%, reflecting considerable fluctuation. Indicating all the sample fall under the permissible limit of 10µgL^{-1} according to WHO (2017).

3.11 Arsenic (As)

The As concentration in the water samples is presented in Table 1, it ~~was~~ ranged from 0.52 to 14.51, 0.32 to 15.18, 0.05 to 4.94, 0.42 to 4.91 and 0.54 to 4.86 µgL^{-1}with a mean value 2.79, 1.89, 1.24, 1.59 and 2.70 µgL^{-1} in Narsinghpur, Narmdapuram, Harda, Partly Raisen (Bareli) and Partly Sehore (Raheti) district, respectively. Over all, it ranged from 0.05 to 15.18 µgL^{-1} with a mean value 1.97 µgL^{-1} and The CV% ranged from 79.2% (Narmdapuram) to 103.55% (Narsinghpur). Over all the samples fall under the permissible limit of 10 µgL^{-1} according to WHO (2017).

Table 1 Status and distribution of heavy metals in irrigation water in central ~~narmada~~Narmada valley zone

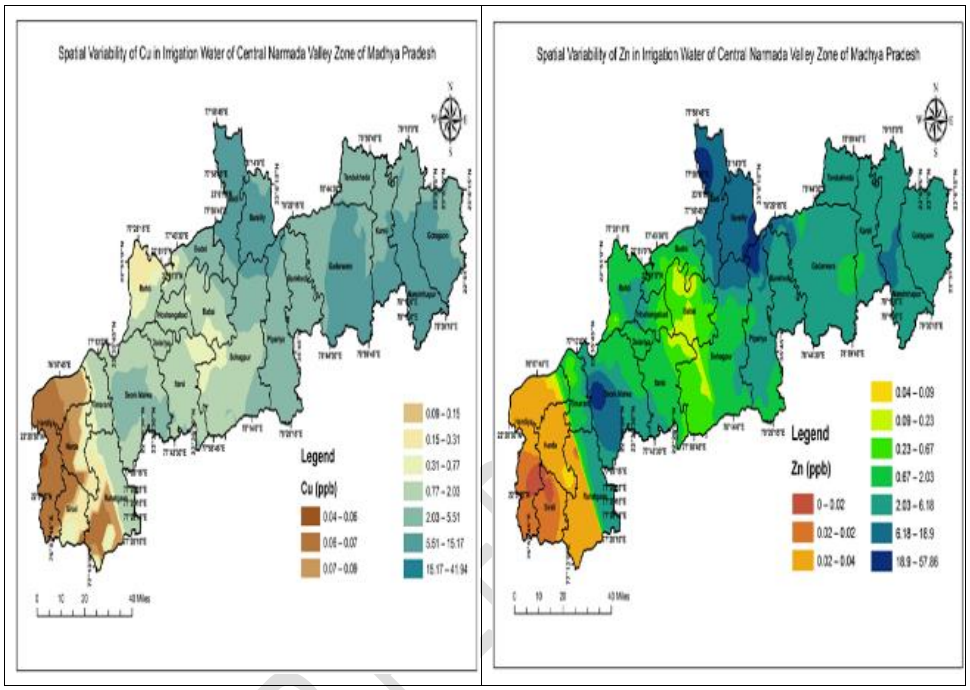
Parameters		Narsinghpur (n=28)	Narmdapura (n=42)	Harda (n=26)	Partly Bareli (n=6)	Partly Raheti (n=2)	Over all (n=104)
Cu	**Min**	0.3	0.04	0.04	0.3	0.08	0.04

(μgL^{-1})	**Max**	41.94	22.41	0.19	13.46	0.17	41.94
	Mean	6.92	3.29	0.08	4.75	0.12	3.49
	CV%	120.51	164.51	39.59	109.19	50.69	176.02
	Min	0.090	0.004	0.009	0.250	0.012	0.004
Zn	**Max**	24.242	57.864	0.111	29.159	0.031	57.864
(μgL^{-1})	**Mean**	5.185	5.269	0.032	11.622	0.022	4.203
	CV%	96.299	38.184	139.13	111.533	159.861	42.601
	Min	1.74	0.02	0.01	3.99	0.05	0.01
Mn	**Max**	380.06	752.57	5.87	210.91	0.07	752.57
(μgL^{-1})	**Mean**	55.4	54.95	0.44	55.64	0.06	40.43
	CV%	158.24	257.24	302.11	143.88	32.05	257.96
	Min	0.05	0.01	0.01	0.04	0.01	0.01
Fe	**Max**	1.50	2.44	0.27	2.57	0.03	2.57
(mgL^{-1})	**Mean**	0.34	0.22	0.04	0.90	0.02	0.24
	CV%	97.95	53.28	57.17	89.91	141.42	56.04
	Min	0.916	0.010	0.001	3.923	0.012	0.001
Cr	**Max**	231.823	133.089	0.090	39.681	0.013	231.823
(μgL^{-1})	**Mean**	20.581	10.176	0.013	13.273	0.013	10.420
	CV%	47.986	41.743	79.816	93.287	1767.767	37.152
	Min	0.15	0.06	0.01	0.18	0.2	0.01
Co	**Max**	3.48	3.94	1.42	1.12	0.24	3.94
(μgL^{-1})	**Mean**	0.79	0.67	0.29	0.48	0.22	0.58
	CV%	97.35	113.41	114.09	69.58	11.62	114.93
	Min	1.09	0.83	0.29	1.19	2.49	0.29
Ni	**Max**	18.58	49.31	5.45	10.43	15.56	49.31
(μgL^{-1})	**Mean**	6.36	5.4	1.94	4.52	9.03	4.81
	CV%	65.4	159.33	69.19	77.15	102.36	129.88
	Min	0.002	0.002	0.002	0.005	0.009	0.002
Cd	**Max**	0.671	30.351	0.092	0.167	0.012	30.351
(μgL^{-1})	**Mean**	0.087	0.770	0.025	0.057	0.011	0.344
	CV%	61.999	16.455	112.75	91.339	494.975	11.569
	Min	0.001	0.001	0.001	0.001	0.001	0.001
Hg	**Max**	0.254	0.357	0.004	0.166	0.004	0.357
(μgL^{-1})	**Mean**	0.024	0.024	0.002	0.029	0.003	0.019
	CV%	45.356	38.557	213.02	43.808	117.851	36.322
	Min	0.34	0.01	0.01	0.74	0.02	0.01
Pb	**Max**	24.05	6.51	1.36	13.46	0.11	24.05
(μgL^{-1})	**Mean**	2.78	1.17	0.36	4.67	0.06	1.58
	CV%	63.64	73.80	89.21	90.25	92.36	53.41
As(μgL^{-1})	**Min**	0.52	0.32	0.05	0.42	0.54	0.05
	Max	14.51	15.18	4.94	4.91	4.86	15.18
	Mean	2.79	1.89	1.24	1.59	2.7	1.97
	CV%	103.55	79.2	99.25	94.87	88.22	87.02

3.12 Spatial variability map of Heavy metals using GIS

Maps showing heavy metal concentrations in the Irrigation water ~~heavy metals maps~~, developed ~~usi~~using GIS and spatial analysis techniques ~~on based maps for irrigation water quality~~, have been an

important means of obtaining well-supported, accurate and critical information in spatial visualization and comparative evaluation of water quality parameters .(Fig. 3,4.5)



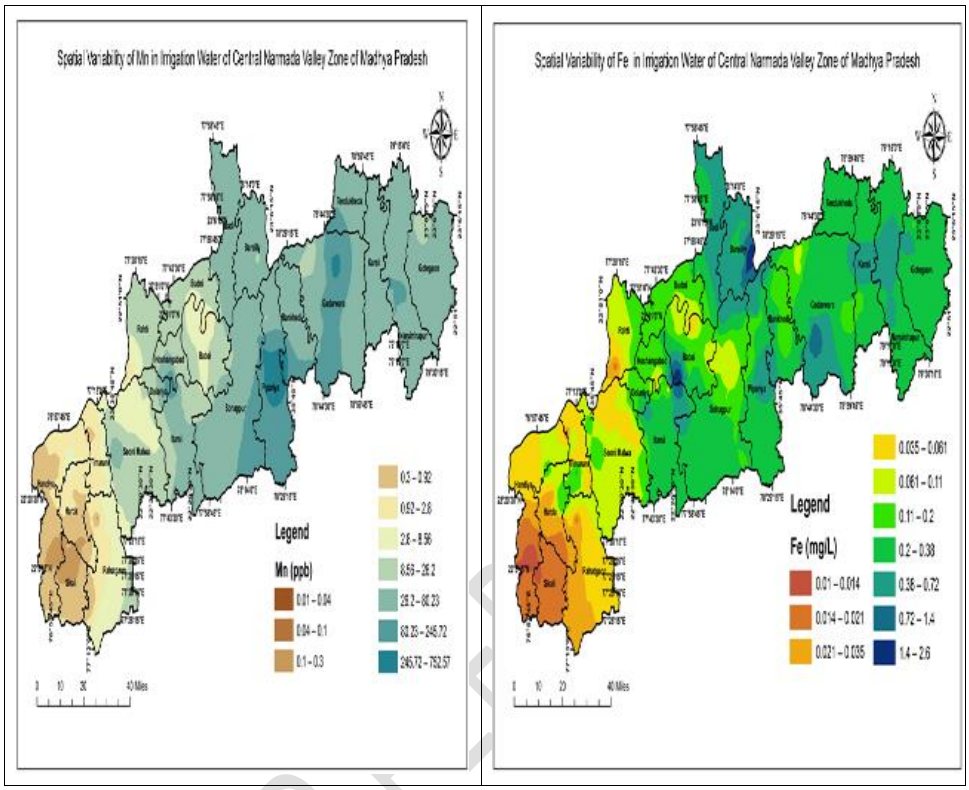
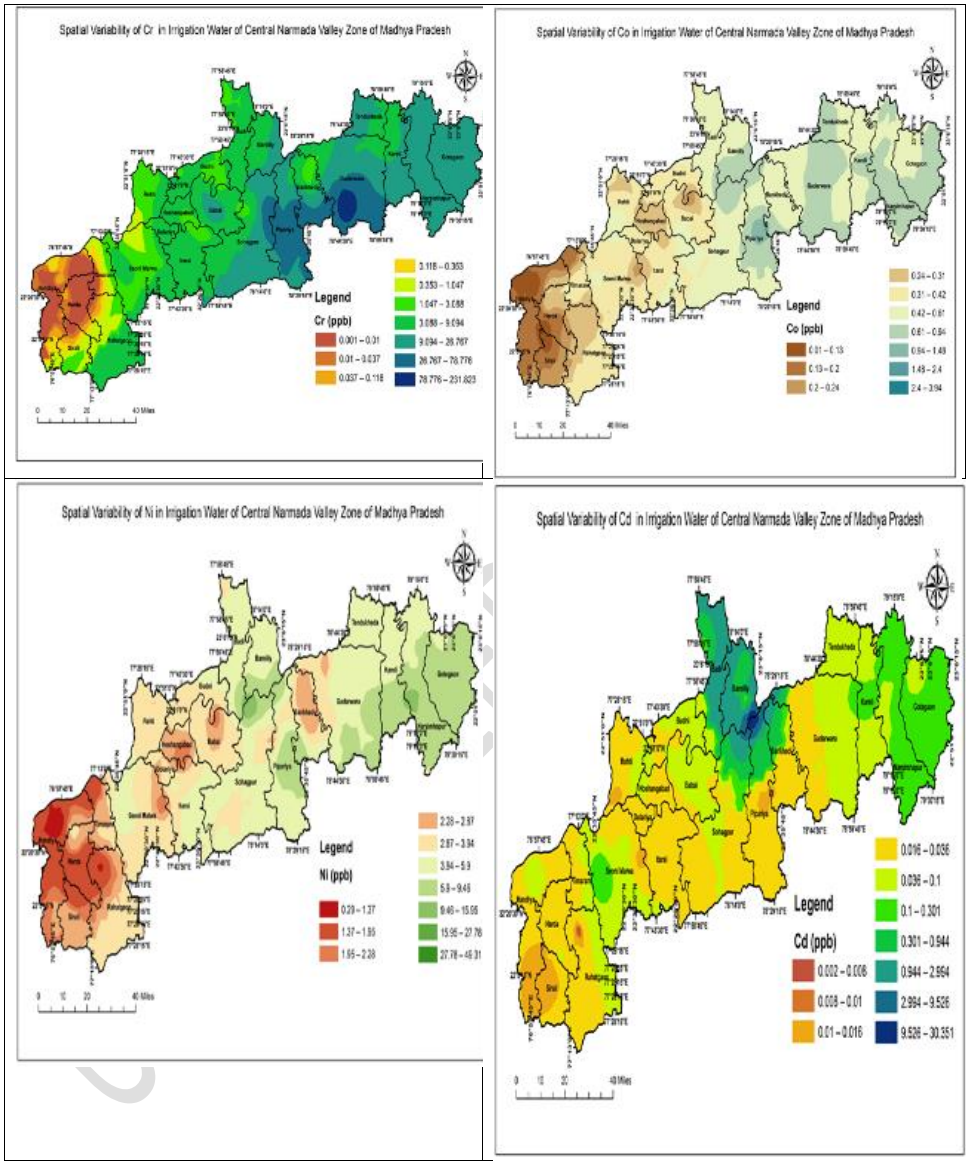


Fig. 3 Spatial Variability maps Cu, Zn, Mn and Fe in irrigation water


Spatial Variability of Cr in Irrigation Water of Central Narmada Valley Zone of Madhya Pradesh
Legend
Cr (ppb)
0.001 – 0.01
0.01 – 0.037
0.037 – 0.118
0.118 – 0.353
0.353 – 1.047
1.047 – 3.088
3.088 – 9.094
9.094 – 26.787
26.787 – 78.776
78.776 – 231.923
Spatial Variability of Co in Irrigation Water of Central Narmada Valley Zone of Madhya Pradesh
Legend
Co (ppb)
0.13 – 0.2
0.2 – 0.24
0.24 – 0.31
0.31 – 0.42
0.42 – 0.57
0.57 – 0.84
0.84 – 1.48
1.48 – 2.4
2.4 – 3.94
Spatial Variability of Ni in Irrigation Water of Central Narmada Valley Zone of Madhya Pradesh
Legend
Ni (ppb)
0.29 – 1.37
1.37 – 1.95
1.95 – 2.28
2.28 – 2.87
2.87 – 3.84
3.84 – 5.9
5.9 – 9.46
9.46 – 15.95
15.95 – 27.76
27.76 – 46.31
Spatial Variability of Cd in Irrigation Water of Central Narmada Valley Zone of Madhya Pradesh
Legend
Cd (ppb)
0.002 – 0.006
0.006 – 0.01
0.01 – 0.016
0.016 – 0.036
0.036 – 0.1
0.1 – 0.301
0.301 – 0.944
0.944 – 2.994
2.994 – 9.526
9.526 – 30.351

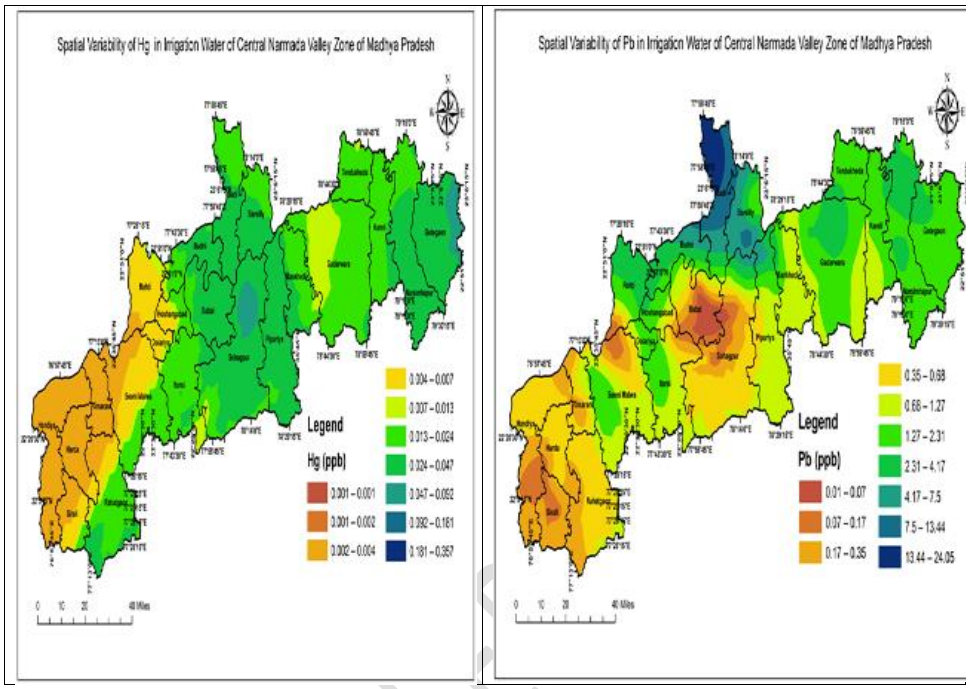


Fig. 4 Spatial Variability maps Cr, Co, Ni, Cd, Pb and Hg in irrigation water

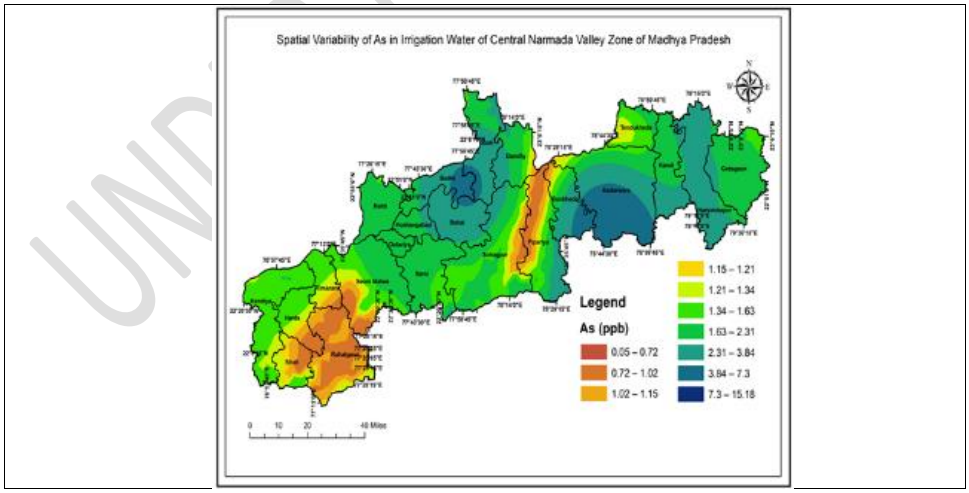


Fig. 5 Spatial Variability map As in irrigation water

4. CONCLUSION

The study revealed significant variability in metal concentrations across the study area. While the metal concentrations generally fall within WHO's permissible limits for irrigation, the high CV% in several metals indicates the need for more consistent monitoring and potential remediation in areas of high fluctuation. Despite the irregular contamination patterns, the overall water quality found to be suitable for irrigation purposes. However, continued monitoring is required to maintain safe water standards.

Commented [Dr-APR5]: Need to be elaborated. Please give the range of observed concentrations and discuss the districts/areas with relatively higher heavy metal concentrations.

5. REFERENCE

Abosede, A., Solomon, O., Peter, A., Eromosele, H., Emmanuel, A. (2018). Wastewater conservation and reuse in quality vegetable cultivation: Overview, challenges and future prospects. *Food Control*, 98, 489–500.

Abuzaid A.S., Abdel-Salam M.A., Ahmad A.F., Fathy H.A., Fadl M.E. and Scopa A. (2022). Effect of marginal-quality irrigation on accumulation of some heavy metals (Mn, Pb, and Zn) in TypicTorripsamment soils and food crops. *Sustainability* 14 106.

Agoro M.A., Adeniji A.O., Adefisoye M.A. and Okoh O.O. (2020). Heavy metals in wastewater and sewage sludge from selected municipal treatment plants in Eastern Cape province, *South Africa. Water* 12(10):2746.

Ahmed M., Matsumoto M. and Kurosawa K. (2018). Heavy metal contamination of irrigation water, soil, and vegetables in a multi-industry district of Bangladesh. Int J Environ Res 12:531–542.

Ahmed M., Matsumoto M., Ozaki A., Thinh N. and Kurosawa K. (2019). Heavy metal contamination of irrigation water, soil, and vegetables and the difference between dry and wet seasons near a multi-industry zone in Bangladesh. *Water* 11(3):583.

Akhtar S., Khan Z.I., Ahmad K., Nadeem M., Ejaz A., Hussain M.I. and Ashraf M.A. (2022). Assessment of lead toxicity in diverse irrigation regimes and potential health implications of agriculturally grown crops in Pakistan. *Agric Water Manag* 271:107743.

Arefin M.T., Rahman M.M., Wahid-U-Zzaman M. and Kim J.E. (2016). Heavy metal contamination in surface water used for irrigation: functional assessment of the Turag river in Bangladesh. *Appl Biol Chem* 59(1):83-90.

Azimi, A., Azari, A., Rezakazemi, M., &Ansarpour, M. (2017). Removal of heavy metals from industrial wastewaters: a review. *ChemBioEng Reviews*, *4*(1), 37-59.

Balkhair K.S. and Ashraf M.A. (2016). Field accumulation risks of heavy metals in soil and vegetable crop irrigated with sewage water in western region of Saudi Arabia, Saudi. *J Biol Sci* 23(1):S32-S44.

Bhuiyan M.A.H., Islam M.A., Dampare S.B., Lutfar Parvez L. and Suzuki S. (2010). Evaluation of hazardous metal pollution in irrigation and drinking water systems in the vicinity of a coal mine area of northwestern Bangladesh. *J Hazard Mater* 179(1-3):1065-1077

Chabukdhara M., Munjal A., Nema A.K., Gupta S.K., Kaushal R.K. (2016). Heavy metal contamination in vegetables grown around peri-urban and ur ban-indus- trial clusters in Ghaziabad, India, *Hum. Ecol. Risk Assess*, 22(3), 736–752.

Faouzi J., Kaioua S., Allali A., Eloutassi N. and Lahkimi A. (2022). Impact of irrigation water on heavy metal content in irrigated soils and plants – spatial and vertical distribution. Ecol. Eng. *Environ. Tech.* 23(5):91-98.

Flouchi, R., Elmniai, A., ben Abbou, M., Touzani, I., Fikri-Benbrahim, K. (2021). Network Water Qual ity at a Hospital Center in Morocco: Bacteriologi cal Survey and Relationship with Human Health. *Journal of Ecological Engineering*, 22(9), 185191.

Jamali G. (2009). Heavy Metal Pollution in Surface Soil in the Vicinity of Abundant Railway Servicing Workshop in Kumasi Ghana. Int. J. Envtal. Res., 2(40), 359-364.

Jena V., Ghosh S., Pande A., Maldini K. and Matic N. (2019). Geo-accumulation index of heavy metals in pond water sediment of Raipur. *Biosc Biotech Res. Comm.* 12(3):585-588.

Kumar, M. and Avinash, P. 2012. A review of permissible limits of drinking water. *Indian J. Occup. En viron. Med.,* 16, 40–44.

Leblebici Z. and Kar M. (2018). Heavy metals accumulation in vegetables irrigated with different water sources and their human daily intake in Nevsehir, *J. Agric. Sci. Technol*., 20(2), 401–415.

Meng W., Wang Z., Hu B., Wang Z., Li H. and Goodman R.C. (2016). Heavy metals in soil and plants after long term sewage irrigation at Tianjin China: a case study assessment, *Agric. Water Manage*, 171, 153–161.

Rattan R.K., Datta S.P., Chhonkar P.K., Suribabu K. and Singh A.K. (2005). Long-term impact of irrigation with sewage effluents on heavy metal content in soils, crops and groundwater – a case study. *Agriculture Ecosystem and Environment*, 109(3 4), 310–322.

WHO (World Health Organization) (2017). Guidelines for irrigation water quality, *4th edn. Incorporating the first addendum,* pp. 1–631.

Woldetsadik, D., Drechsel, P., Keraita, B., Itanna, F. and Gebrekidan, H. (2017). Heavy metal accumulation and health risk assessment in wastewater-irrigated urban vegetable farming sites of Addis Ababa, *Ethi opia, Int. J. Food Contam.,* 4(1), 9.

Zhou, H., Yang, W., Zhou, X., Liu, L., Gu, J., Wang, W., Zou, J., Tian, T., Peng, P.and Liao, B. (2016). Accu mulation of heavy metals in vegetable species plant ed in contaminated soils and the health risk assessment. *Int. J. Environ. Res. Public Health*, 13, 289.