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TRACE METAL ANALYSIS IN GROUNDWATER OF THE HANDRI RIVER BASIN, KURNOOL DISTRICT, ANDHRA PRADESH, INDIA

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ABSTRACT

Quantitative analysis of trace metals in the groundwater of the Handri river basin was conducted using Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES). Descriptive statistics, box whisker plots, and GIS assessed their spatial distribution in South India. The elements arsenic, cadmium, and iron were the most abundant, with iron having the highest concentration and copper the lowest. Chromium, copper, nickel, and zinc complied with BIS and WHO standards for drinking water. In certain locations of the Handri river basin, elevated concentrations of arsenic, cadmium, iron, lead, and manganese were found to be polluting and endangering the water. A comprehensive analysis revealed that, out of 41 water quality sites, copper, chromium, nickel, and zinc were within acceptable limits, while arsenic and cadmium exceeded the limits. Twenty groundwater sites showed elevated iron content, revealed by a spatial distribution map. Excessive manganese and lead levels were observed in specific stations, such as Gorantla, Bondi Madugula, Ramachandrapuram, Konganapadu, and Tangaradona. The study suggests that population growth and industrialization contribute to resource depletion and environmental deterioration. The cohesive findings from descriptive models, box whisker plots, and spatial analyses aim to guide decision-makers in developing adaptive groundwater trace element monitoring strategies for the Handri basin in Kurnool district, India.

Keywords: Trace elements, Geographic Information System, Permissible limit, Water Quality, WHO and BIS.

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INTRODUCTION

Trace elements, are elements found in very small amounts in a sample or environment, play essential roles in the regular development of living organisms. Nevertheless, the presence of these substances in groundwater is undesirable due to their potential to be toxic, particularly in locations such as rural and urban regions where groundwater is the major informant of drinking water. The presence of arsenic in groundwater is broadly acknowledged as worldwide environmental concern that impacts millions of people (WHO, 2019). Lead, cadmium, and arsenic possess deleterious impacts on human health and freshwater ecosystems, placing them among the WHO's foremost 10 compounds of utmost public apprehension (WHO, 2019). The occurrence of heavy minerals in groundwater is impacted by several factors, such as the type of aquifer, mineral erosion, rainfall, water quality, and the duration of residency.[1-3] Specific trace elements, like copper, iron, manganese, and zinc, are necessary for biological processes, whereas arsenic, cadmium, and lead can be dangerously drawn at minimal levels, presenting hazards to public health.[4] Humans are exposed to higher quantities of trace metals through their skin, by consuming them, and by breathing them in. This exposure is mainly caused by using water that is contaminated for drinking and other household activities. In developing nations, public water sources are frequently utilized, but surface water may become polluted by both human-made and natural origins, such as industrial and urban runoff wastewater.[4] The presence of high levels of trace metals in water bodies presents considerable health risks, as these toxic substances are incorporated into the food chain. The presence of trace elements in soil is a significant issue, worsened by changing climate patterns and the excessive use of agrochemicals. This poses hazards to the lifetime of individuals and hampers the growth of plants.[5,6] This study focuses on evaluating the water quality of the Handri River in times of trace metal concentrations. The river serves as a conduit

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for several types of garbage, including municipal and industrial waste, agricultural runoff, and mining waste. Specific heavy metals, including Cu, Hg, Pb, Sn, and Zn, are very poisonous and can pose significant dangers to the system when present in elevated amounts.[7,8,9] Cadmium and mercury, which are both poisonous metals, upset enzyme function by establishing chemical interactions with sulfhydryl groups present in enzymes. The main quantitative of this research is to comprehend the hydrogeochemical mechanisms that lead to high levels of heavy elements in the groundwater of the Handri basin, located in Kurnool, Andhra Pradesh, India. The specific aim is to determine the origins of these metals and the factors that control their levels. This study also considers the potential health concerns for humans that may face exposure to trace metals. To mitigate the risk of trace element contamination in the food system, it is imperative to tackle the issue of trace element toxicity in soil, specifically in industrial areas where soil pollution is a significant issue.[7]

Toxicity of Metals

Certain trace elements, often referred to as heavy metals, pose significant toxicity risks, especially when present at elevated concentrations. Notable heavy trace metals, including Cu, Hg, Pb, Sn, and Zn, can be harmful to biological systems.[10] Elemental metals such as Fe, along with toxic metals like Cd and Hg, fall under the category of trace metals. These metals often exhibit strong affinities for sulfur and form linkages with sulphydryl groups in enzymes, thereby inhibiting enzymatic functions. Despite this, the sources and processes governing trace metal concentrations in groundwater remain elusive. The focus of this investigation is to identify hydrogeochemical processes and sources contributing to high trace metal concentrations in the Handri River basin, Kurnool, Andhra Pradesh, India, and assess the associated risks to human health.

Arsenic

Arsenic, a certainly occurring trace element, is extensively circulated in the environment. It is a relatively rare element found in the atmosphere, rocks, groundwater, and organisms.[11,12] Various human activities and geographical events, such as biological processes, weathering effects, and volcanic emissions, contribute to its presence.[13] While most arsenic-related environmental issues stem from natural events, however anthropogenic activities like mining, fossil fuel combustion, and the use of arsenical herbicides and pesticides have significant negative impacts.[14,15] Despite a reduction in arsenical product usage,[16] wood preservation remains a persistent source. Arsenic poisoning, whether organic or inorganic, affects hundreds of millions of people globally.

Cadmium

Traces of cadmium are naturally present in the Earth's crust, and once released into the environment, it persists in soils and sediments. Plants gradually absorb cadmium, accumulating it in their tissues, and it moves up the food chain, eventually reaching humans. Cadmium concentrations in contaminated river waters might be below detection levels, and permissible levels in drinking water are established based on health considerations.[13] Industrial activities such as plating works, cadmium dye plants, and sewage processing plant effluents contribute to surface water pollution.[17]

Chromium

Chromium, the twenty-first most abundant element globally, is found in rocks, volcanic dust, plants, animals, and seawater. It exists in trivalent and hexavalent forms, with trivalent chromium being a vital component in our bodies.[16,17] Excessive amounts of trivalent chromium can inhibit metabolic processes, even it is beneficial for glucose metabolism. Industries like chrome plating, stainless steel, tanning, electroplating, wood treatment, and paints use chromium. Hexavalent chromium (Cr VI) is a known human lung carcinogen.[18]

Copper

Copper, a naturally occurring trace element essential for human growth, is sourced from electrical and steel industries, copper mining, smelting, weathering, sewage, and sludge. In potable water, copper concentrations can be elevated in new water pipe systems, posing potential harm to children. Recommended copper concentrations in drinking water are set to avoid nerve damage, liver, and kidney disease.[19] The permissible copper concentration in consumption water is 50 μg/L, with relaxation up to 1500 μg/L when no alternative water source is accessible.

Iron
Iron, the most abundant heavy metal in the Earth's crust, plays a vital role in the sustenance and development of living organisms. In acidic environments, iron's solubility increases when present as ferrous (Fe^{2+}) and ferric (Fe^{3+}) ions. Engaged in various metabolic activities, including oxygen transfer and DNA synthesis, excessive iron levels can lead to tissue damage due to the generation of free radicals. Monitoring iron levels in human tissues is crucial to prevent adverse health effects.[20]

Lead
Lead is an extremely hazardous metal whose usage has resulted in significant environmental degradation and health issues in different localities of the world. The major contributors of lead exposure are batteries, cosmetics, contaminated soil, food, gasoline, household dust, industrial emissions, lead paints, toys, and water.[21] Some side effects of lead poisoning include teratogenic effects, inhibition of hemoglobin synthesis, cardiovascular dysfunctions, reproductive problems, severe damage to central and peripheral nervous systems, joint problems, gastrointestinal problems, urinary tract infections with blood in urine, neurological issues, and permanent damage to the brain.[22] The water transported through pipes made of lead and its components can contaminate the water.[23]

Nickle
When nickel is taken insufficiently or excessively, signs of insufficiency or toxicity may appear as nickel is an essential nutritional trace metal in a few species of animals, plants, and microorganisms. Nickel (Ni) is the 24th most abundant element in the Earth's crust, constituting around 3% of the Earth's composition.[24] Pyrhotite and garnierite are the primary sources of nickel. Nickel concentrations are rising in a few areas due to man-induced activities such as mining and smelter emissions, consumption of coal and oil, and use of fertilizers, sewage, pesticides, and phosphates.[25] Inhalation exposure at the work place is a primary route to nickel-induced toxicity that can have harmful effects on the respiratory and immune systems.[26] It is also known to affect people handling stainless steel and nickel products, causing allergic contact dermatitis.[27]

Zinc
All living organisms, including humans, need zinc. The synthesis and translation of genetic material is aided by zinc-containing proteins and enzymes.[28] Zinc metal is an important component of the human diet, requiring between 4 to 10 mg per day, based on age, and up to 16 mg/day for pregnant women. Zinc is mostly obtained from food sources. Oral consumption of zinc is generally regarded to be safe, but excessive levels can disrupt the body's systems and hinder reproduction and growth. The clinical manifestations of zinc toxicosis encompass symptoms such as diarrhea, hematuria, emesis, icterus (mucous membrane yellowing), anemia, as well as renal and hepatic failure.[19]

Study area
The Handri basin research area is between 15°14'1" and 15°53'40" North latitudes and 77°20'13" and 78°9'25" East longitudes. The study site is located around 2 km west of Kurnool, Andhra Pradesh, and extends over an area of around 3398.54 km^2 (Fig.-1). The entire length of the river from its source is 136.02km. It is bounded by the nallamalas and Erramalas mountain ranges which run parallel from north to south. The Erramalas divide the district into well-specified stretches from East to West. The Handri, a tributary of the Tungabhadra, rises in the Maddikera fields in Maddikera Mandal, receives a stream from Erramalas at Laddagiri village in Kodumur mandal, and joins with Thungabhadra at Kurnool. It drains most of Maddikera, Pathikonda, Devanakonda, Gonegandla, Kodumur, and Kallur mandals. This is a turbid current that rises and falls abruptly. The land here slopes from south to north and is drained by the river Handri, which meets the Tungabhadra River at Kurnool. The soils in the northwestern areas traversed by the Handri River are mainly black cotton, while the soils in the southeastern areas are predominantly pure red soil. The upper parts and middle sections of the Handri drainage basin are comprised of Archeans and Dharwar formations which are composed of granites, granite gneiss, hornblende gneiss, biotite gneiss, volcanic, conglomerate, metarhyolite, metandacite, meta basalt, and amphibolite. The lower part is

occupied by Kurnool formations which include shale, limestone, quartzite, massive limestone, flaggy limestone, and quartz with conglomerate.

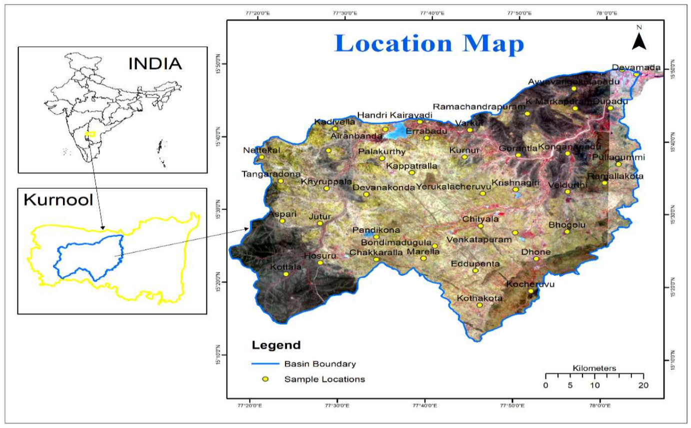

Fig.-1: Study Area Map of Handri River Basin

EXPERIMENTAL

Material and Methods

Groundwater samples were obtained from 41 distinct sites within the Handri River watershed from May to December 2020. The specific locations and their corresponding coordinates are provided in Table-2. Before being collected, the sample bottles were prepared by immersing them in a solution of 10% HNO_3 for a duration of 24 hours and then rinsed thrice with double distilled water (DW)[20,21]. Following that, 500 mL water samples were acquired and immediately subjected to treatment with 2 mL of ultrapure nitric acid (a 1:1 mixture of 50 mL concentrated HNO_3 and 50 mL distilled water) together with 2 mL of HCl to regulate the pH of arsenic to 2. The samples were then stored at a temperature of 4°C in sampling kits until they were transported to the laboratory for analysis of trace metals. In the laboratory, the water samples underwent filtration using a membrane filter that had a pore size of 0.45 μm[22,23]. The experiment utilized chemicals and reagents acquired from Merck India, whereas the standard metal solutions were supplied from Merck Germany. The study exclusively utilized deionized water, and all glassware and equipment were meticulously purified with deionized water prior to usage. The analysis of trace metals was conducted using Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) in accordance with the 2012 recommendations established by the APHA[24,25].

RESULTS AND DISCUSSION

Table-3 shows the concentrations of trace metals detected in the research region for the period of May 2019 to December 2019. The box plots depict the levels of As, Cd, Cr, Cu, Fe, Mn, Ni, Pb, and Zn in groundwater samples (see Fig.-2). Examination of the lowest, average, and highest amounts of As, Cd, Mn, and Fe at most sample sites indicates that their heightened concentrations exceed the acceptable thresholds for potable water. In contrast, the box plot for concentrations of Cr, Cu, Ni, Pb, and Zn displays levels that are lower than the prescribed limit. In contrast to elements such as As, Cd, Cr, Mn, and Zn, the box lengths for Cu, Fe, Ni, and Pb are considerably larger, suggesting considerable differences in geographical distribution, as seen in Fig.-2. The observed fluctuation can be explained by the presence of abnormally high concentrations of iron in the groundwater system at multiple sampling sites in the study area.

Arsenic

The permissible threshold for arsenic in potable water, as determined by the World Health Organization (WHO) and the Bureau of Indian Standards (BIS), is defined at 0.01 mg/L (10 μg/L). The concentration of arsenic in groundwater samples within the studied region ranges from 182.5 μg/L to 1212 μg/L. The Kothakota village recorded the lowest arsenic concentration at 182.5 μg/L, while Jutur village exhibited the highest concentration, constituting about 42.5% of the total constituents. It is noteworthy that all groundwater samples in the research area surpassed the permissible limits set by both BIS and WHO (refer to Fig.-3).

Cadmium

The WHO and the BIS advise that the highest acceptable level of cadmium in drinking water should not exceed 0.003 mg/L. Within the research area under study, the concentrations of cadmium in groundwater varied from 14.25 µg/L to 17.05 µg/L during the PRM season and from 12.58 µg/L to 15.38 µg/L during the POM season. The settlement of Konganapadu had the highest concentration, at 17.05 µg/L (Fig.-4). Significantly, every groundwater sample in the study area surpasses the predefined thresholds set by both the WHO and BIS.

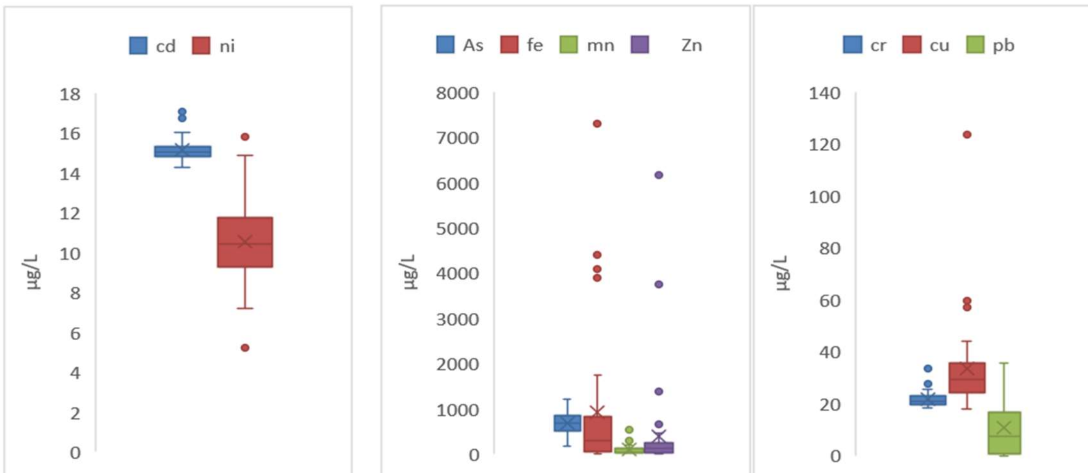

Fig.-2: Box Whisker Diagram (May. 2020 To Dec. 2020)

Table-3: Pre-Monsoon Trace Metal Distribution in Handri River Basin

Sampling Station	As mg/L	Cd mg/L	Cr mg/L	Cu mg/L	Fe mg/L	Mn mg/L	Ni mg/L	Pb mg/L	Zn mg/L
Dupadu(Daba)	32.43	15.17	21.33	21.59	68.11	19.85	12.95	0.90	7.54
Gorantla	30.76	17.02	22.71	37.88	25.23	39.86	14.81	14.52	12.50
Konganapadu	20.60	17.06	24.98	31.51	42.29	20.03	5.21	26.00	34.13
pullagummi	18.04	15.09	18.46	26.70	13.69	19.28	11.49	0.00	2.80
Ramallakota	24.29	14.96	19.71	23.27	13.06	19.41	10.78	0.00	3.09
Krishnagiri	21.20	14.86	22.62	31.13	40.49	33.04	10.46	0.00	4.01
Yerukalacheruvu	35.56	14.86	19.72	37.23	28.16	23.31	10.31	0.00	27.64
Veldurthi	24.57	16.72	19.87	24.32	19.67	27.65	9.65	3.36	11.13
Chityala	22.36	15.07	21.08	29.36	29.46	22.42	9.94	10.50	25.48
Venkatapuram	22.12	15.53	20.74	23.81	35.38	17.80	9.17	0.04	52.12
Bhogula	19.62	15.48	19.86	23.67	41.84	20.07	11.11	0.21	20.14
Dhone	22.63	14.47	19.58	21.26	16.81	22.88	10.98	0.00	13.37
Bondimadugula	27.57	15.06	21.04	41.86	67.79	36.94	11.99	0.47	25.49
Marella	20.42	15.27	22.90	44.10	35.60	22.30	12.22	14.59	60.13
Eddupenta	26.94	14.25	21.33	57.17	94.10	31.96	12.27	0.00	21.42
Kocheru	14.31	15.01	19.35	18.02	53.97	18.54	12.03	0.00	1.90
Kothakota	15.35	14.28	22.60	29.37	40.03	19.88	10.28	0.00	3.42
Devamada	26.00	15.21	20.70	27.68	72.86	23.09	10.94	6.21	16.20
Lic Colony	33.23	14.61	18.47	59.77	38.87	19.30	10.37	0.00	19.16
A.Gokulapadu	26.23	15.03	24.38	59.50	73.07	11.45	14.87	0.00	12.34
K.Markapuram	36.77	15.14	23.42	24.17	31.95	21.15	9.66	0.00	44.16

Ramachendrapuram	84.01	15.16	33.40	12.37	40.93	54.42	15.83	18.45	13.90
varkur	25.20	15.83	23.68	41.24	82.28	32.15	8.23	0.00	15.87
Airanbanda	27.44	15.25	22.68	24.90	12.49	30.81	9.47	0.00	11.04
Handri Kairavadi	34.08	14.93	23.19	26.15	30.19	23.41	7.77	0.00	20.47
Kadivella	27.33	14.77	19.54	35.56	20.48	20.62	9.01	0.00	5.65
B.Agraharam	25.90	14.53	21.38	30.55	38.81	43.48	10.66	0.00	27.89
Palakurthy	28.07	15.14	20.43	26.18	40.82	28.31	14.63	0.00	37.54
Errabadu	21.16	14.39	19.85	21.19	13.33	19.11	8.78	0.00	29.71
Kurnur	21.38	14.79	18.63	27.33	34.78	21.72	11.13	0.00	13.29
Kappatralla	17.48	14.65	20.44	27.15	11.89	32.53	7.20	0.00	38.18
Devanakonda	22.41	15.43	23.65	24.75	28.09	18.45	9.44	0.00	80.12
Khyruppala	36.60	15.12	20.82	29.58	13.94	33.52	9.36	0.00	46.12
Nettekal	24.55	14.80	20.20	23.99	20.20	20.54	8.65	0.00	18.89
Tangaradona	45.45	16.01	20.35	32.05	17.33	77.25	10.94	35.74	61.56
Aspari	22.54	14.25	19.16	32.69	12.55	21.58	7.69	0.00	27.23
jutur	30.16	15.89	27.64	33.35	81.48	80.45	11.27	7.39	64.43
Kottala	37.14	14.89	19.80	24.36	23.92	20.04	11.01	0.00	48.76
Hosuru	68.10	15.36	21.38	31.96	82.53	21.33	8.36	0.00	6.10
Pandikona	25.67	15.04	22.28	35.72	72.56	15.20	12.16	0.00	18.76
chakrala	23.55	14.89	25.46	29.84	43.94	15.12	10.26	0.00	17.70
Min	14.31	14.25	18.46	12.37	11.89	11.45	5.21	0.00	1.90
Max	84.01	17.06	33.40	59.77	94.10	80.45	15.83	35.74	80.12
Avg	28.52	15.15	21.68	30.84	39.15	27.32	10.57	3.38	24.91

Table-4: Post-Monsoon Trace Metal Distribution in Handri River Basin

Sampling station	As mg/L	Cd mg/L	Cr mg/L	Cu mg/L	Fe mg/L	Mn mg/L	Ni mg/L	Pb mg/L	Zn mg/L
Dupadu(Daba)	29.67	13.50	19.36	19.70	65.88	17.55	11.19	0.45	5.41
Gorantla	28.00	15.35	20.74	35.99	23.00	37.56	13.05	14.07	10.37
Konganapadu	17.84	15.39	23.01	29.62	40.06	17.73	3.45	25.55	32.00
pullagummi	15.28	13.42	16.49	24.81	11.46	16.98	9.73	-0.45	0.67
Ramallakota	21.53	13.29	17.74	21.38	10.83	17.11	9.02	-0.45	0.96
Krishnagiri	18.44	13.19	20.65	29.24	38.26	30.74	8.70	-0.45	1.88
Yerukalacheruvu	32.80	13.19	17.75	35.34	25.93	21.01	8.55	-0.45	25.51
Veldurthi	21.81	15.05	17.90	22.43	17.44	25.35	7.89	2.91	9.00
Chityala	19.60	13.40	19.11	27.47	27.23	20.12	8.18	10.05	23.35
Venkatapuram	19.36	13.86	18.77	21.92	33.15	15.50	7.41	-0.41	49.99
Bhogula	16.86	13.81	17.89	21.78	39.61	17.77	9.35	-0.25	18.01
Dhone	19.87	12.80	17.61	19.37	14.58	20.58	9.22	-0.45	11.24
Bondimadugula	24.81	13.39	19.07	39.97	65.56	34.64	10.23	0.02	23.36
Marella	17.66	13.60	20.93	42.21	33.37	20.00	10.46	14.14	58.00
Eddupenta	24.18	12.58	19.36	55.28	91.87	29.66	10.51	-0.45	19.29
Kocheru	11.55	13.34	17.38	16.13	51.74	16.24	10.27	-0.45	-0.23

Kothakota	12.59	12.61	20.63	27.48	37.80	17.58	8.52	-0.45	1.29
Devamada	23.24	13.54	18.73	25.79	70.63	20.79	9.18	5.76	14.07
Lic Colony	30.47	12.94	16.50	57.88	36.64	17.00	8.61	-0.45	17.03
A.Gokulapadu	23.47	13.36	22.41	57.61	70.84	9.15	13.11	-0.45	10.21
K.Markapuram	34.01	13.47	21.45	22.28	29.72	18.85	7.90	-0.45	42.03
Ramachendrapuram	81.25	13.49	31.43	10.48	38.70	52.12	14.07	18.00	11.77
varkur	22.44	14.16	21.71	39.35	80.05	29.85	6.47	-0.45	13.74
Airanbanda	24.68	13.58	20.71	23.01	10.26	28.51	7.71	-0.45	8.91
Handri Kairavadi	31.32	13.26	21.22	24.26	27.96	21.11	6.01	-0.45	18.34
Kadivella	24.57	13.10	17.57	33.67	18.25	18.32	7.25	-0.45	3.52
B.Agraharam	23.14	12.86	19.41	28.66	36.58	41.18	8.90	-0.45	25.76
Palakurthy	25.31	13.47	18.46	24.29	38.59	26.01	12.87	-0.45	35.41
Errabadu	18.40	12.72	17.88	19.30	11.10	16.81	7.02	-0.45	27.58
Kurnur	18.62	13.12	16.66	25.44	32.55	19.42	9.37	-0.45	11.16
Kappatralla	14.72	12.98	18.47	25.26	9.66	30.23	5.44	-0.45	36.05
Devanakonda	19.65	13.76	21.68	22.86	25.86	16.15	7.68	-0.45	77.99
Khyruppala	33.84	13.45	18.85	27.69	11.71	31.22	7.60	-0.45	43.99
Nettekal	21.79	13.13	18.23	22.10	17.97	18.24	6.89	-0.45	16.76
Tangaradona	42.69	14.34	18.38	30.16	15.10	74.95	9.18	35.29	59.43
Aspari	19.78	12.58	17.19	30.80	10.32	19.28	5.93	-0.45	25.10
jutur	27.40	14.22	25.67	31.46	79.25	78.15	9.51	6.94	62.30
Kottala	34.38	13.22	17.83	22.47	21.69	17.74	9.25	-0.45	46.63
Hosuru	65.34	13.69	19.41	30.07	80.30	19.03	6.60	-0.45	3.97
Pandikona	22.91	13.37	20.31	33.83	70.33	12.90	10.40	-0.45	16.63
chakrala	20.79	13.22	23.49	27.95	41.71	12.82	8.50	-0.45	17.84
Min	11.55	12.58	16.49	10.48	9.66	9.15	3.45	-0.45	-0.23
Max	81.25	15.39	31.43	57.88	91.87	78.15	14.07	35.29	77.99
Avg	25.76	13.48	19.71	28.95	36.92	25.02	8.81	2.93	22.84

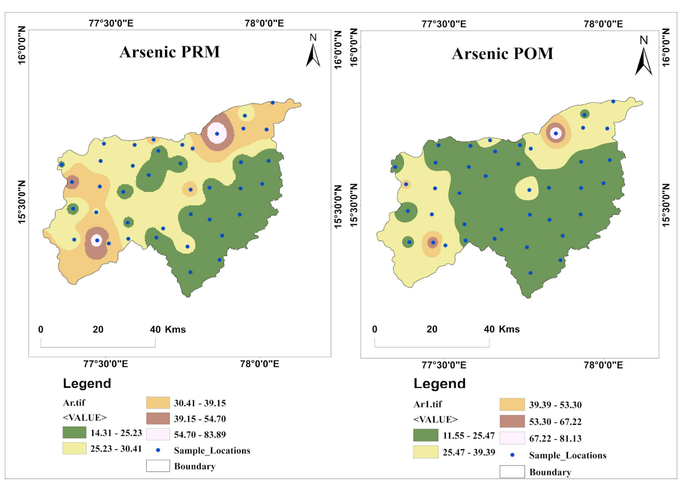

Fig.-3: Arsenic for the PRM and POM for the Study Area

Chromium

The BIS suggests a maximum allowable chromium concentration of 0.05 mg/L in drinking water. Chromium levels in the studied area vary from 18.46 µg/L to 33.37 µg/L before the PRM season and from 16.49 µg/L to 31.40 µg/L POM, with the peak value (33.37 µg/L) detected in Ramachandrapuram (Fig.-5). Notably, all samples within the research region comply with the acceptable limits set by the WHO and BIS.

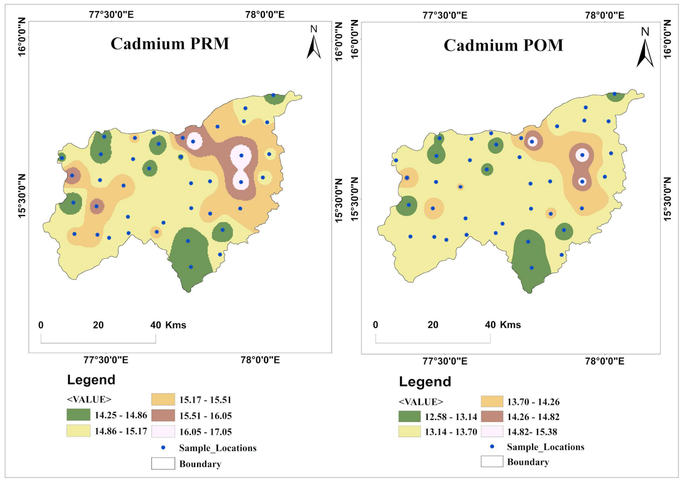

Fig.-4: Cadmium for the PRM and POM for the Study Area

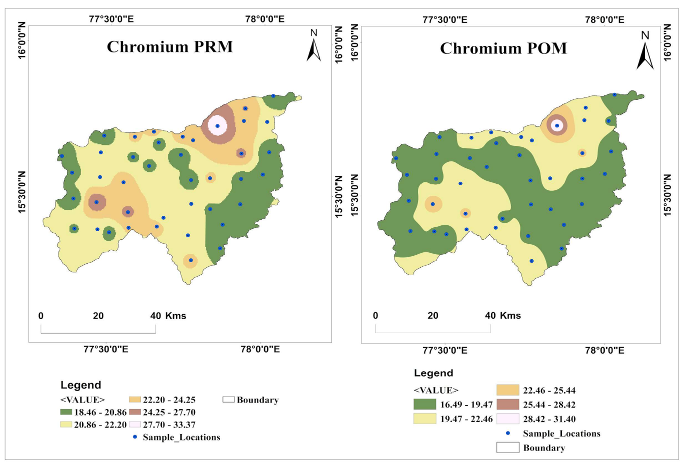

Fig.-5: Chromium for the PRM and POM for the Study Area

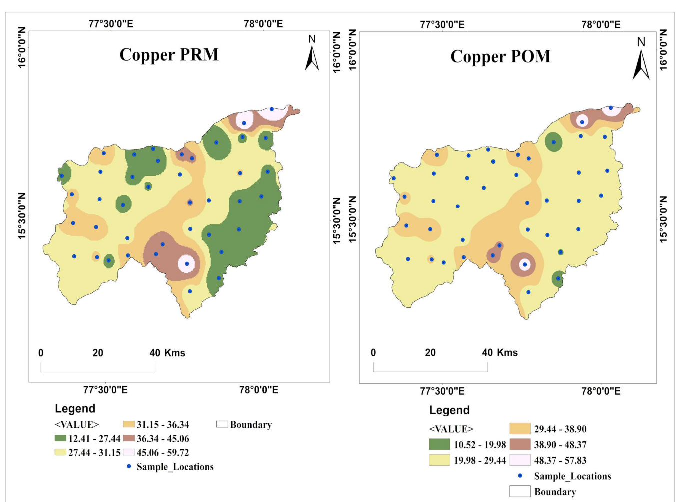

Fig.-6: Chromium for the PRM and POM for the Study Area

Copper

The recommended concentration of copper in drinking water is 50 µg/L, with a relaxation to 1500 µg/L permitted if no alternative water source is available. In the Handri basin, copper values ranged from 12.41 µg/L to 59.22 µg/L PRM and from 10.52 µg/L to 57.83 µg/L POM. These low levels of Cu suggest the absence of a significant pollution source. The highest values of copper (59.22 µg/L) were observed in Ramachandrapuram, possibly due to domestic waste and runoff from extensive agricultural areas.[21] Importantly, all water samples-maintained copper levels within acceptable limits, below those set by both the BIS and WHO. A contour map was generated using the average copper content throughout the entire research period (Fig.-6).

Iron

As per the standards set by BIS, the permissible level of iron is 0.3 mg/L (300 µg/L). In river water, the iron content varies between 11.90 µg/L and 94.08 µg/L during the PRM period, while in the POM period, it ranges from 9.67 µg/L to 91.86 µg/L. Notably, Kocheruvu exhibits the lowest concentration at 9.67 µg/L, whereas A. Gokulapadu records the highest concentration at 94.08 µg/L (Fig.-7). It is noteworthy that concentrations above the acceptable limits are observed only in specific locations, such as A. Gokulapadu, while the remaining samples conform to the acceptable limits outlined by BIS.

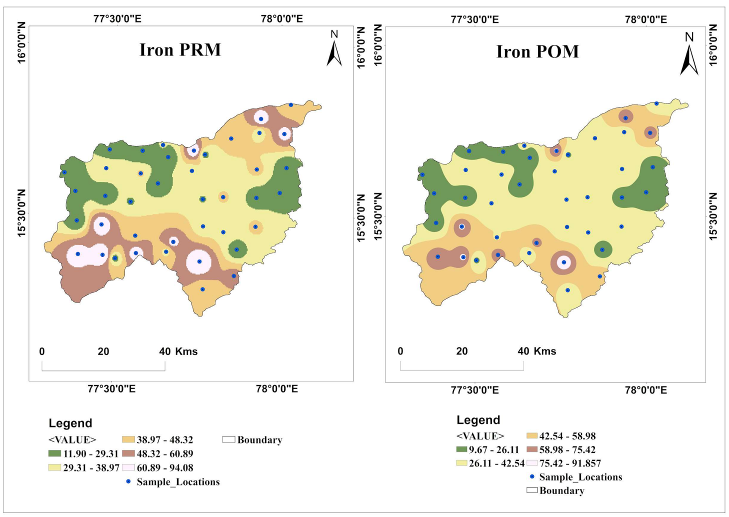

Fig.-7: Iron for the PRM and POM for the Study Area

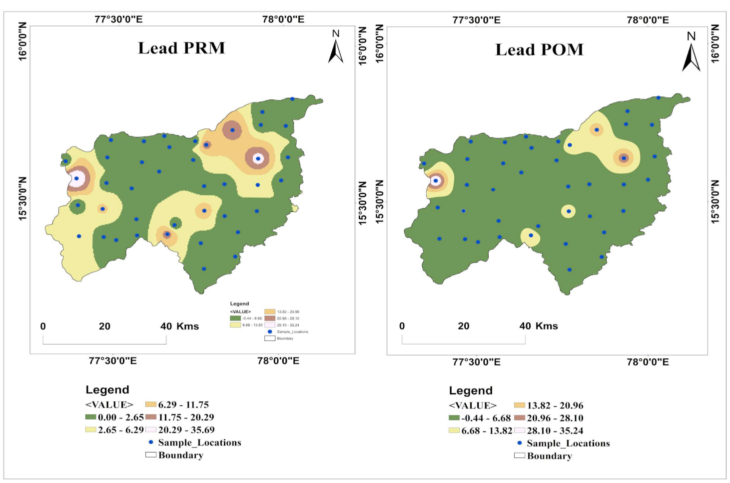

Fig.-8: Lead for the PRM and POM for the Study Area

Lead

For lead in drinking water, the BIS has specified a level of 0.01 mg/L (10 g/L). At Tangaradona water quality site, the lead content is at its highest (35.69 g/L) (Fig.-7). The three sampling stations Chityala (10.5

µg/L), Gorantla (14.52 µg/L), and Marella (14.59 µg/L) have concentrations above the acceptable limit, whereas the other three sampling stations Kottala (18.45 µg/L) and Tangaradona (35.74 µg/L) have concentrations exceeding the permissible limit of 15 µg/L, as specified by BIS (Fig.-8).

Manganese

According to the standards set by the BIS, the permissible level of manganese is 0.3 mg/L. The quantity of iron present in river water exhibits a range of 11.45 µg/L to 80.36 µg/L during the PRM period, and during the POM period, it fluctuates between 9.15 µg/L and 78.06 µg/L. Kocheruvu registers the lowest concentration at 9.15 µg/L, whereas A.Gokulapadu records the highest concentration at 80.36 µg/L (refer to Fig.-9). While the concentration values for some samples exceed the acceptable limits, most of the samples fall within the permissible range established by BIS.

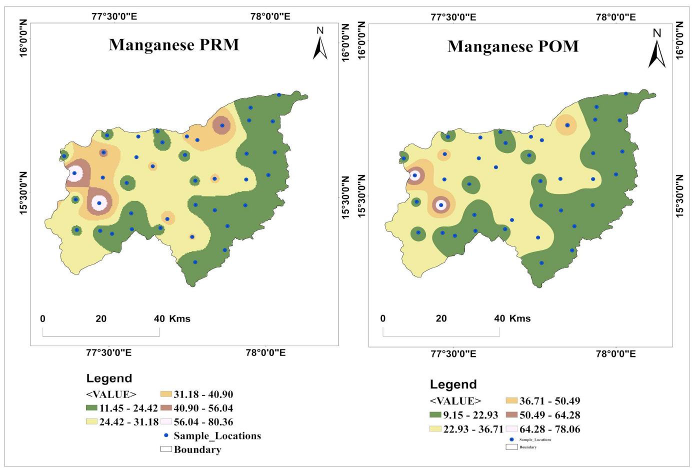

Fig.-9: Manganese for the PRM and POM for the Study Area

Nickle

In drinking water, the BIS,2012 recommends a nickel concentration of 0.02 mg/L (Fig.-10). Ramachandrapuram has the highest concentration of nickel (15.82 µg/L) (Fig.-10). Further without any relaxation of nickel in drinking water it is found to be under the WHO and BIS 10500-2012 standards in all sample stations.

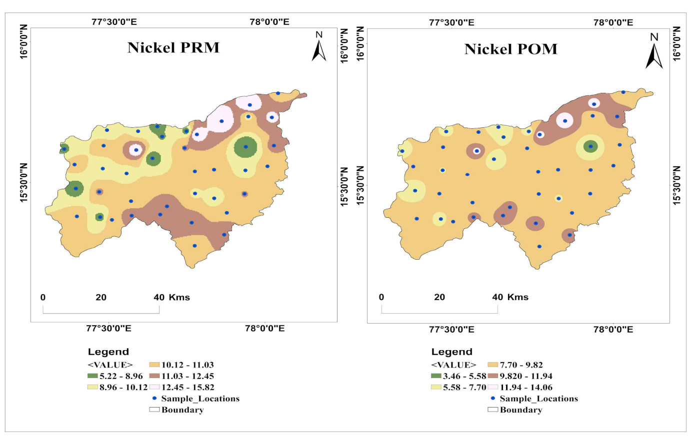

Fig.-10: Nickel for the PRM and POM for the Study Area

Zinc

In the absence of alternative sources, the BIS suggests maintaining a zinc concentration of 5 mg/L in drinking water, with the option to increase it to 15 mg/L (Fig.-11). Zinc levels in water range from 1.92 gm per liter to 80.09 µg/L, with the Tangaradona sampling station on the river Handri recording the highest zinc content at 80.09. It is noteworthy that within the research area, all zinc concentrations observed in water quality assessments remain well below the acceptable and authorized limits set by the BIS, indicating the absence of zinc toxicity in the river water.

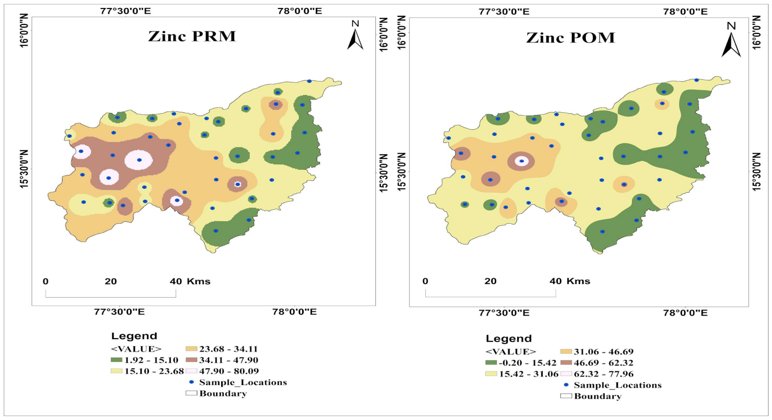

Fig.-11: Zinc for the PRM and POM for the Study Area

CONCLUSION

The analysis of the data involved employing descriptive statistics, box whisker plots, and GIS to assess the dataset. The results revealed that the Handri River basin displayed elevated concentrations of arsenic, cadmium, and iron metals. Specifically, iron exhibited the maximum concentration, while Cd demonstrated the lowest. Notably, the levels of Ar, Cd, Cr, Fe, and Zn fell within the regulatory limits established by the BIS and WHO. It can be inferred that rapid industrialization and the subsequent population growth have led to environmental degradation and the depletion of natural resources. Examination of groundwater samples from the Handri basin indicated pollution at specific locations, rendering the water unfit for consumption. Arsenic, cadmium, iron, manganese, and lead concentrations exceeded permissible limits, while other metal concentrations remained within safe levels. Comprehensive analysis across 41 water quality sites revealed arsenic and cadmium concentrations surpassing permitted limits at all locations. Iron concentrations exceeded the permitted level at 20 sites, with no relaxation, while other results fell within acceptable ranges. Manganese concentrations at certain locations exceeded acceptable limits, while Bondimadugula, Gorantla, and Ramachandrapuram had concentrations surpassing permissible limits set by BIS in 2012. Lead concentrations exceeded acceptable limits at Gorantla, Chityala, and Marella stations, and surpassed permissible limits at Konganapadu, Ramachandrapuram, and Tangaradona stations. The main contributors to the presence of arsenic, cadmium, manganese, iron, and lead in the river basin are the disposal of solid waste and sewage from nearby cities, human settlements, agricultural runoff, and soil erosion. The rivers' condition has worsened due to the discharge from municipal and industrial watersheds. The study's results are expected to assist decision-makers in developing adaptive monitoring systems for trace elements in groundwater of Handri basin, Kurnool district, India.

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CONFLICT OF INTERESTS

The author (s) declares that there is no conflict of interest in this research and manuscript.

AUTHOR CONTRIBUTIONS

All the authors contributed significantly to this manuscript, participated in reviewing/editing, and approved the final draft for publication.

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