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Analysis of Different Metals in Groundwater and Its Toxicity in Plants

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ABSTRACT

Both rural and urban parts of the world, groundwater is an essential reservoir of freshwater Due to drainage and consequently rising pollution are a serious risk to the planet's ability to provide safe water supplies. For both health and medical practitioners, water that has been polluted by heavy metals-specifically, the elements cadmium, arsenic, nickel, copper, lead, manganese, and mercury-is developing a serious health risk. The main objective of this research was to evaluate the amount of heavy metals in the groundwater of the Kanker district in the Indian state of Chhattisgarh's Northern Bastar region. In the premonsoon period in May-June of the study region, samples were taken using manually operated pumps, tube wells, and dug wells at 15 distinct locations. The amount of each element, including Pb, Mn, Zn, and Fe, was measured with an atomic absorption spectrophotometer (AAS) and the appropriate digestion technique. The water samples had mean concentrations of metallic elements in an order: Fe>Pb>Zn>Mn. The outcome of this study was that the extent of accumulation of heavy metals in water samples is significantly greater than the recommended limitation, indicating that residents and the environment around them may be at risk.

Keywords: Groundwater, Heavy metals, Toxicity in plants, Atomic Absorption Spectrophotometer.

INTRODUCTION

The purity of water is instinctively related to the health of people, decreasing poverty, promoting equality among men and women, assuring food safety, supporting livelihoods, protecting environments, and encouraging economic and social progress in our communities.[1] For many millions of individuals, groundwater is an important resource for agriculture and drinking.[2] When it comes to using groundwater for commercial, agricultural, and residential uses, the composition of the water plays a significant role. Because of growing urbanization and the Industrial Revolution, land use varies widely and ignores environmental laws and regulations. This leads to significant variations in the quality of groundwater over small areas, which severely limits economic growth worldwide.[3] The release of hazardous metals through industrial and metropolitan runoff into aquatic environments is an international environmental concern in the modern period.

Harmful chemical substances have been continuously poisoning water bodies at higher levels in the last few years because of the simultaneous development of activity by humans along rivers. Metals that are toxic constitute the most significant pollutants and cause concern due to their persistent prevalence in water as well as soil, which exposes geo-ecological systems into danger and alters natural biogeochemical processes.[4] The lack of water is a worldwide issue, and sewage treatment has become more significant for sustaining the increasing consumption of groundwater.[5]

There have been reports of polluted water in more than seventy nations, exposing an enormous amount of people at risk across the world. Such metallic ions may accumulate on soil surfaces and groundwater and pose a threat to human health. The groundwater is affected by irrigation practices; industrial waste water is a major issue; and transition elements are significant pollutants that are not degraded naturally.[6] Contamination by heavy metals is a major global issue due to their persistence, resilience, accumulation, and non-biodegradability. If a person drinks polluted water, such hazardous metals may enter their body. Such dangerous elements may get into the human body by contacting aquatic organisms, ingestion of polluted water, or dermal contact with water that is polluted. Prolonged intake of metals can cause neurological, musculoskeletal, and physical issues in addition to the lethal illnesses such as Parkinson's, Alzheimer's, cancer, and multiple sclerosis.

Overview of the study area: Chhattisgarh, India

This region in the middle of India has an abundance of assets of nature, including forests, rivers, and minerals. The diversified topography of the state includes field's hills, and mountains. This region's soils are abundant in heavy metals, including cobalt, lead, zinc, copper, and chromium. Many studies have been conducted on the possible toxicity and health danger that heavy metals present in Chhattisgarh's soils and water provide to humans.[6]

Research done in 2006 by Pandey *et al.,* finds that the District Kanker, an area where there has previously been serious pollution, has new regions of contamination with arsenic. Included reports of elevated levels of arsenic in the soil, plants, and aquatic life of the Kanker district and its surrounding area, as well as in both groundwater and surface water. The amounts of trace elements (Aluminum, Boron, Arsenic, Beryllium, Cadmium, Barium, Cobalt, Copper, Iron, Chromium, Antimony, Nickel, Lithium, Tin, Manganese, Zinc, Vanadium, and Selenium) were detected in a total of 160 samples of groundwater that were taken in the rural region of Bastar, India's central region, between the pre-monsoon and post-monsoon periods by Pervez *et al.,* 2021 According to Gupta *et al.,* (2023), the entire condition of the groundwater in the Kanker district of Chhattisgarh and the negative effects of toxic metals on vegetation and human beings are assessed.

The majority of the study's chosen areas are rural areas, and it was discovered that those living nearby are mostly unaware of the guidelines for the purity of the drinking water they drink. Furthermore, in spite of the significance of having clean drinking water, there are not many scientific investigations that assess the research area's quality of groundwater and the potential risks to well-being that come with it, particularly among the rural communities.[9] Determining the levels of toxic metals and metalloids in borehole water for drinking from fifteen distinct sites in the Kanker area of Chhattisgarh, India, was the aim of this study. The findings obtained from this research could provide information on prospective water quality that can be used for manufacturing, farming, and consumption in the provinces of Kanker district of Chhattisgarh, India.

Heavy metals in water

Now a days, "metal trace elements" are frequently used in place of "heavy metals," as they comprise both dangerous as well as less poisonous heavy elements. Most of the metal trace elements turn dangerous when concentrations are above a permissible level. Even extremely low concentrations of mercury, lead, nickel, zinc, cadmium, chromium, and copper (less than 0.01 mg/L) have a significant negative impact on human health.[10]

The two main causes of water contamination are industrialization and urbanization. The metals are transferred into the sediments of aquatic environments by drainage from towns, cities, villages, and companies. When pollutants are transported to reservoirs of water, they can still pose a serious threat to people and other living things. The degree of toxicity associated with heavy metals depends on a number of elements, such as the kind of element that exists, its biological activity, how long the organism was exposed, and the length of time the living thing was exposed. It is normal behavior for people to throw garbage from residences and industries into the drainage systems. Persistent contaminants, including toxic metals, can then enter the digestive tract via marine species, for example, seafood, and have an impact on predators, which include bigger fish, mammals, bird species, and people. After that, these predators leave and carry the pollutants to other regions.[11]

Human Toxicity after Exposure to HMs

Arsenic

Generally, a small amount of the arsenic is eliminated by the skin, hair, and nails. When inorganic As is consumed, it passes through the circulatory system, binds to haemoglobin molecules, and transmits to several organs, including the renal system, liver, and respiratory tract, where it gradually accumulates. Several studies have reported the accumulated form of As in different kinds of cells via its biological transformation via enzymatic regulation. As a result, arsenic accumulates in the testes, lung tissue, the kidneys, and liver. Several types of cancer, especially those of the skin, urinary tract, respiratory tract, liver, kidneys, and prostate, are caused by prolonged contact with inorganic arsenic.[12]

Chromium

Numerous negative consequences of chromium on the immunological system in humans are well-known. Numerous experimental investigations have examined the impact of chromium on the defence mechanism. Elevated levels of hexavalent chromium diminish and reduce the humoral immune response and alveolar macrophage phagocytic activity. Furthermore, two kinds of hypersensitive reactions are brought on by chromium: type IV, or delayed type, and type I, or anaphylactic type. Numerous studies have also reported the development of allergic contact dermatitis as a result of chromium exposure.[13]

Although high quantities of chromium from heavy releases of this metal in surface waters can harm fish gills close to discharge locations, chromium does not generally accumulate in fish bodies. Chromium deficiency in animals can result in tumor development, infertility, genetic abnormalities, respiratory issues, and weakened immune systems. Chronic chromium poisoning in humans can cause mucous membranes, skin rashes, respiratory issues, and even Broncho pulmonary malignancies.[10]

Lead

Drinking water can also cause lead poisoning. Groundwater can get contaminated by pipelines used for transporting it that are made up of lead and its related substances. According to the Environmental Protection Agency, the Pb has been proven to be a carcinogen. Lead has a significant impact on several parts of the body. Ninety-five percent of the lead found in the body accumulates as phosphate that is not soluble in extremely thin bones, and lead absorption initially depends on the flow of blood to various organs. Lead toxic property, also known as lead hurting, can be extremely potent or everlasting. Excessive exposure may result in tiredness, anxiousness, inflammation in the joints, attacks of migraines, gastrointestinal disorders, renal malfunction, cerebral trips, high blood pressure, and dizziness. The workplace and several manufacturing sectors that use lead are the main areas in which severe exposure occurs. Continuous exposure to lead can result in mental impairment, abnormalities at birth, mental illness, hormonal imbalances, hypersensitivity, a learning disability, loss of weight, impulsivity, and other conditions.[14]

Cadmium

Cadmium finds significant uses in the following fields: electronic devices, metallurgy, soldering, batteries, TVs, materials such as ceramics, photographing, pesticides, and electrolysis. It may enter the environment through many processes, such as purifying metal ore, coloring agents, metal alloys, semiconductors, detergents, phosphate fertilizers, and petroleum-based chemicals. Another source of cadmium is battery cells containing nickel-cadmium compounds. In excess Cd can harm the organs such as the kidneys, bones, and arteries and veins. According to reports, there might be a possibility of cancer risk from cadmium exposure.[15]

Nickel

The soils and rocks from volcanic eruptions are rich in nickel. Ni and its associated salts found significant applications in industry in the fabrication of Ni-Cd batteries, as well as in the electrolysis of stainless steel, coins, car and aviation parts, spark plugs, and beauty products. It organically finds how to get into reservoirs by the process of weathering of rocks and soils and through the breakdown of minerals. The main sources of pollution in aquatic environments are the nickel salts, which dissolve in water. Neighboring water bodies are polluted by paint formulas and the enamel industry's potentially hazardous nickel-containing chemicals. Cigarettes also contain nickel, but in the form of nickel carbonyl, a volatile chemical. Although nickel is required for the biosynthesis of RBCs, excessive quantities of the metal can be harmful. While living cells are not impacted by amounts of nickel, prolonged high-exposure exposure can cause cell damage, a low weight, liver and heart failure, and other health problems. Decrease in proliferation of cells, tumours, and harm to the neurological system can all result from nickel toxicity.[15]

Mercury

Mercury is an element that can accumulate in ecological systems and travel through water systems.[16] Another dangerous heavy metal that exists within our surroundings is mercury. It may undergo the methylation process, resulting in the production of methyl mercury that can reach into the food chain. Metallic Hg can easily pass through the membrane of the placenta and blood-brain barrier because it attaches with the red blood cells. Certain amounts of mercury are taken up by the brain and nervous system, even though most of it immediately oxidizes to mercuric mercury. Mercury is present in several body tissues, including the pancreas, the epidermis, mouth and sweat glands, respiratory tract, enterocytes, prostate gland, testes, mother's milk, muscles, liver, the adrenaline glands, and the thyroid gland. T cell functioning is also affected by the metal's high affinity to groups of sulphydryl on T cell surfaces.[11]

Copper

Both the growth of bones and the formation of enzymes require a small amount of copper. In general, there are three main forms of copper that can be found in the environment: Cu0 (metallic), Cu+ (cuprous), and Cu^{2+} (cupric). Of these, it is discovered that the Cu^{2+} type of Cu is highly dangerous and commonly found in nature. Because of the changes between Cu^{2+} and Cu^{+}, Cu may also be poisonous. It has the potential to produce hydroxyl and superoxide radicals. Furthermore, consuming too much copper damages cells, which can result in Wilson's disease, Parkinson's disease, and Alzheimer's disorders in people as well as death. The steel, fertilizer, electrolysis, metallurgy, and mining sectors are the main sources of copper. Below the World Health Organization's and other standards-specified limit, copper is required, even though copper is very poisonous at higher levels and an essential component of nourishment at low levels.[17]

Zinc

A very small quantity of Zn, an essential microelement, is needed to maintain the health of people. Zinc plays a role in the synthesis of hormones, growth, and the strengthening of the immune and gastrointestinal systems. Adverse health consequences result from drinking water with a zinc content that is either higher or less than the recommended level. Excessive Zn can cause a number of health issues, including artery disease, digestive problems, skin irritation, vomiting, nausea, anemia, pancreatic duct difficulties, and metabolism of proteins issues. A Zn insufficiency enhances the possibility for diabetes and can cause problems with fertility.[18]

Table 1: The permissible limit of heavy metals in water, sources and their impact

Metals	Sources	Impact	MCL (mg/L)	Refernces
Lead	Burning coal, electroplating, making batteries, mining, and producing pigments	appetite loss, fetal brain damage, and renal damage	0.006	[19][27]
Chromium	Textile, steel fabrication, electroplating, paint production, dyeing, and tanning	headache, nausea, diarrhea, and vomiting	0.05	[19,20,21]
Nickel	Paints, non-ferrous metal, porcelain enameling, and electroplating	Coughing, rashes, persistent asthma, nausea, and carcinogenic	0.20	[19,20,21]
Mercury	Volcanic eruptions, the mining, paint, and paper industries, the weathering of rocks, batteries, and the combustion of coal	effects arheumatic arthritis, problems with the kidneys, heart, and nervous system	0.00003	[19,20,21]
Copper	Copper polishing, mining, painting, plating, and printing	Wilson disease, insomnia, and liver damage	0.25	[19,20,21]
Cadmium	fertilizer, mining, welding, plastics, insecticides, and refinement	renal diseases, carcinogenicity, and kidney failure	0.01	[19,20,21]
Zinc	Brass manufacturing, mining, plumbing, and oil refining	Depression, high levels of stress, complete or partial paralysis, and signs of a neurological disorder	0.80	[19,20,21]

Toxicity in Plants Following Exposure to HMs

Heavy metals and metalloids can play an essential part in the growth of plants as micronutrients (e.g., Fe, Co, Cu, Mn, Zn, and Mo) and by being involved with metabolic activities. If their levels rise above their permissible level, they can be dangerous to the developmental process of plants. The primary standard for classifying heavy metals, density, has been changed everywhere. Extensive research has been conducted worldwide to determine the effects of toxic metals on plants. The plant's capacity for growth can be negatively affected by certain heavy metal ions, particularly those that are extremely poisonous and essential micronutrients.[10]

Cadmium consequences for plants

Plants exposed to lead (Cd) show several kinds of signs, such as chlorosis, slowing of growth, burning of the root tips, and ultimately death. Cadmium affects stomata function, water transport, and cell wall flexibility. The suppression of photosynthesis resulting from photosystem II's susceptibility to excessive levels of Cd and lower stomata permeability in response to poisoning by metals is the other adverse impact caused by Cd. Cd 20 may affect both the donating and decreasing (acceptor) sides of the oxidizing II. As per the 1991 publication of Aery and Sarkar, criteria for soybean growth that include It is observed that root-shoot length, dry weight, leaf area, number of seeds, seed weight, nodule number, and weight all decrease at Cd concentrations greater than 5 g/g. The reduction in the production of chlorophyll and the curvature of the embryo are responses to the growth inhibition caused by Cd.[22]

Chromium consequences for plants

Chromium is a toxic and insignificant metal for vegetation. The negative effects of Cr are mostly caused by the metal speciation, which regulates the metal's absorption, translocation, and accumulation. Plants take in in different ways, Cr(III) and Cr(VI) are the two stable forms of Cr.[23] The problem of plant chromium (Cr) toxicity is complex and impacts various aspects of plant growth, including photosynthesis, oxidative deficiencies, enzyme function, and the growth of seeds. Reports of positive relationships among Cr and certain critical nutrients (Mn, Cu, Ca, Mg, Fe, and Mn) have also rarely been reported. Significant fluctuations in the Cr levels in the roots and leaves of plants exposed to excessive Cr can be detrimental to the plants and cause an iron deficiency with visible consequences. When chromium is present, the quantity of Ca in plants decreases significantly. There have been reports of Mn deficit in *Vigna radiata* and *Brassica oleracea* in response to Cr stress.[22]

Lead consequences for plants

Lead is a metal that has been found to cause toxic effects in plants, however it is not always essential. It has been proven to severely impact the anatomy, activity of enzymes 24 quantity of water, mineral nutrition, and germination of seeds, developing seedlings, and photosynthesis of all plant species. One of the most important effects is likely observed across the whole photosynthesis system of plants, where interference with the electron transport routes reduces the energy transformation efficiency of photosystem II by four to five times (e.g., as tested in wheat). In addition, Pb induces thylakoid membrane disarray, nuclear membrane rupture, chloroplast morphology alterations, and the growth of electrodense deposits in the leaves of vulnerable plants. It has been shown that contact with Pb can cause root cell breakdown and alter the structure of mitochondria in plants.[25]

Arsenic and Mercury consequences for plants

As and Hg are recognized as two of the top five harmful metals/metalloids among all contaminants (Hg, As, Cu, Pb, Cd).[26] A naturally occurring metalloid, arsenic (As) is frequently found in pesticides and wood preservatives. Groundwater contamination in India has led to widespread well contamination, which poses a major risk to public health. Frequent irrigation with tainted water, can poison humans and other animals through food consumption. The two most common Arsenite [AsO_2– or As(III)] and arsenate [AsO_4 –3 or As(V)] are two inorganic arsenic moieties found in terrestrial plants that are detrimental to plants. Aerobic soils are where most arsenate is found. Rather than ATP, ADP-As complexes are what causes cell death[20]. Mercury is hazardous to plants even at low doses of 1 μg L^{-1} Hg in the nutrient solution. Reduced root development, stunted growth, and inhibition of photosynthetic activities are the most prevalent signs of mercury toxicity. Failure of several metabolic activities, including respiration, gas exchange, photosynthesis, and chlorophyll production, is also caused by it. The increased concentration of mercury in the root prevents plants from absorbing K^+. Conversely, it has also been noted that lower Hg concentrations increase K^+ absorption.[22]

Study area

The Kanker District (Fig. 1) is located in the longitudes of 20.6–20.24 and latitudes of 80.48–81.48 in the southern part of Chhattisgarh, India. The overall area of the district is 5285.01 square kilometers. 748,941 people are living there. Red dirt makes up the majority of the topography in the area. Water samples were collected for analysis in June 2023. Particularly, groundwater occurs in phreatic (water desk) conditions and locations beneath semi-limited conditions. The Groundwater Estimation methodology of 1997 has been the main basis for estimating the groundwater sources for the Kanker district.

Table 1: Concentration levels of toxic metals in plants on land (WHO, Canada, and China)[27]

Heavy metals	Herbal substance from Canada (mg/kg)	WHO unit of measurement: mg/kg	China (herbal material) (mg/kg)
Cd	0.3	0.3	1
As	5	Nil	2
Pb	10	10	10
Cr	2	Nil	Nil
Co	23	Nil	Nil
Hg	0.2	Nil	0.5
Cu	Nil	Nil	Nil
Fe	Nil	Nil	Nil
Zn	Nil	Nil	Nil

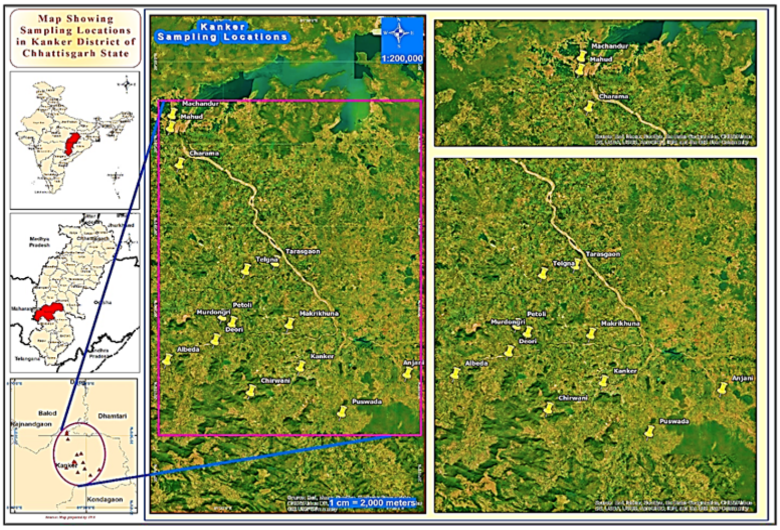

Fig. 1. Map of Sampling Location of Kanker District

MATERIAL AND METHOD

Water sample collection and analysis

A transparent 1-liter plastic bottle held 15 water samples that were taken from every borewell for thorough quantitative examination. Every bottle was thoroughly cleaned before gathering the materials, wash with distilled water, and let air dry water samples. Shortly after the well was pounded for five to ten minutes, the pump wells were removed. To ensure that no residual content accumulated before the water was stored in sterilized containers, field samples of water were filtered using 0.45 mm filtration. The testing facility received the gathered samples and kept them refrigerated. In the Indian state of Chhattisgarh, 15 groundwater samples were drawn from bore wells in the Kanker district. The samples were collected and sent straight to the laboratory in sterile, acid-washed polyethylene terephthalate (PET) bottles. All of the bottles were washed with a metal-free soap after being submerged in a 10% nitric acid solution before being sampled. Water samples were subjected to analysis using AAS (Electronic Cooperation of India Limited) for metalloids comprising Fe, Mn, Zn, and Pb.

RESULT AND DISCUSSION

Heavy metal analysis

Heavy metals and metalloid were measured in borehole drinking water collected from 15 different sampling sites ok Kanker district of Chhattisgarh, India and results of the concentration and mean concentration of heavy metal analyzed in groundwater samples of Kanker district province are presented Table 3 and Fig. 1. The concentration of Iron taken from the all sampling locations Kanker district of ranged from 4.2 to 6.9mg/L. The maximum concentration (6.9mg/L) was observed in WS1 sampling site, while minimum concentration (4.2mg/L) was in sample taken from site WS12. The concentration level of Mn in collected sample was ranged from 0.1mg/L in WS2 to 0.9mg/L in WS7.Zn concentrations in groundwater samples ranged from 0.25mg/L to 0.68mg/L. The highest Zn concentration (0.68mg/L) was observed in the water sample collected in WS4 sampling site. Similarly, the Pb concentrations in groundwater samples ranged from 0.64mg/L (WS10) to 1.32mg/L (WS15).

The mean values of all analyzed heavy metals Fe, Mn, Zn and Pb in all 15 collected ground water samples were 5.47mg/L, 0.32mg/L, and 0.45mg/L and1.001mg/L respectively. The concentrations of Zn, Pb and Fe were higher than the established standards except for Mn. The findings indicate that the irrigating water is polluted chiefly by Fe, Pb and Zn. The possible sources of heavy metals like Pb and Zn Human activities like construction, mining, and industrial processes can increase lead and Zinc in water bodies. Similarly, Kanker district has significant iron ore deposits, which can lead to iron contamination in water bodies.

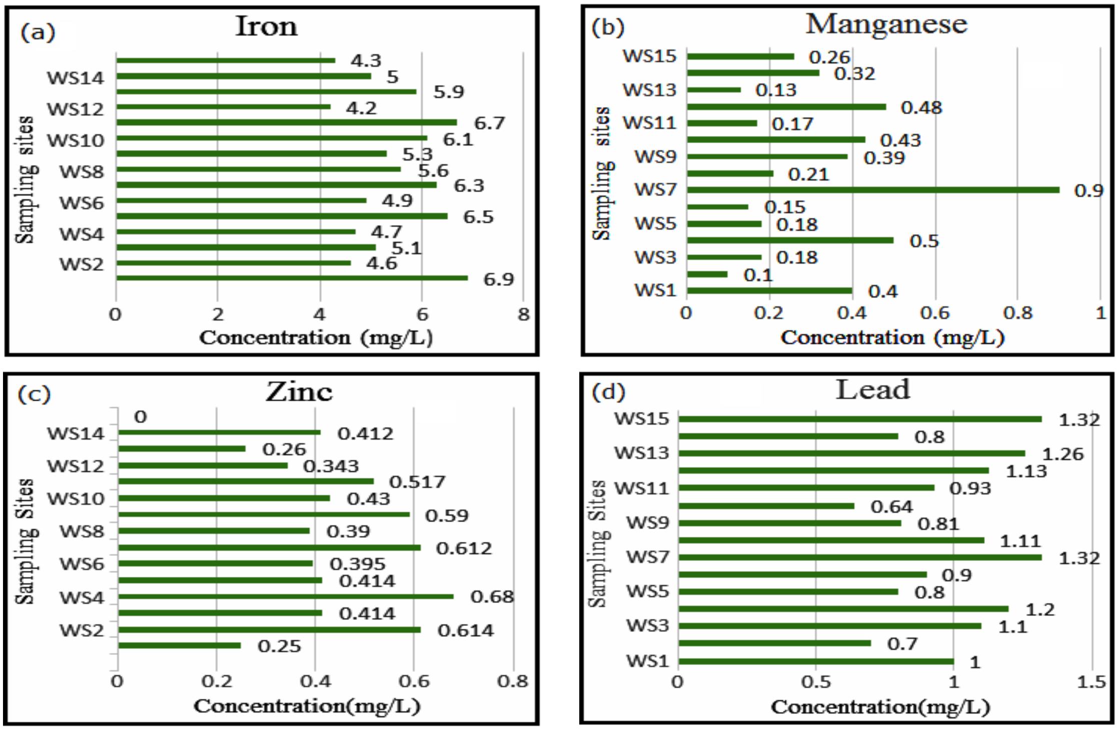

Fig. 2. Heavy metal concentration (mg/L) in water samples (a) Iron (b) Manganese (c) Zinc and (d) Lead

Table 3: Concentration of heavy metal ions in groundwater samples of Kanker District (mg/L)

Water Samples	Fe	Mn	Zn	Pb
WS1	6.9	0.4	0.25	1
WS2	4.6	0.1	0.614	0.7
WS3	5.1	0.18	0.414	1.1
WS4	4.7	0.5	0.68	1.2
WS5	6.5	0.18	0.414	0.8
WS6	4.9	0.15	0.395	0.9
WS7	6.3	0.9	0.612	1.32
WS8	5.6	0.21	0.39	1.11
WS9	5.3	0.39	0.59	0.81
WS10	6.1	0.43	0.43	0.64
WS11	6.7	0.17	0.517	0.93
WS12	4.2	0.48	0.343	1.13
WS13	5.9	0.13	0.26	1.26
WS14	5	0.32	0.412	0.8
WS15	4.3	0.26	0,4	1.32
Min	4.2	0.1	0.25	0.64
Max	6.9	0.9	0.68	1.32
Mean	5.473333	0.32	0.4515	1.001333

CONCLUSION

Present work studied concentration of heavy metals such Fe, Mn, Zn, and PB in 15 ground water samples from borewells and tube wells of different sampling location of Kanker district of Chhattisgarh of Indai. The results of present study indicated that among the 04 studied metals, concentration of iron is higher than standard level in water of Sampling site WS13 (5.9mg/L). The order of heavy metals in the study was Fe>Pb>Zn> Mn based on analyses of their occurrence and concentrations within the research area. Therefore, the information in this paper is beneficial to regulatory authorities, by alerting them to the need for constant monitoring of the SW quality starting from the Environ Monit Assess (2017) 189:480 Page 15 of 16 480 water source, treatment, and packaging stage which will lead to the improvement of human health within the community. Consequently, this study encourages environ mentalists, administrators, and public health workers to create public awareness to avoid the consumption of vegetables grown in contaminated soils, hence reducing health risks.

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Conflict of Interest

We, the authors of this research article declare no conflict of interest.

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