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Heavy Metal Contamination in Agricultural Soil and Ground Water Paonta Sahib

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Heavy metals in soil are linked to fertilizers, both organic and inorganic. Phosphorus in fertilizers adds a lot of Heavy metals to the concentration of Toxic metals (point source). Phosphate pebbles, a byproduct of phosphorus fertilizers that are insoluble in water, are crucial in the process of metal immobilization in soil by precipitation as metal phosphates. Mineral nutrients are needed for plant development and production, and there are a number of these elements. For example, copper, zinc, iron, manganese, molybdenum, nickel, magnesium, calcium, and boron can facilitate: sugar metabolism, nitrogen fixations, respiration, enzyme activity, gene control, pigment production, photosynthesis, ion homeostasis and other cellular processes inside of the plant at minimal levels. Nonetheless, these critical elements have a detrimental effect on the development, growth and reproduction of plants at levels above acceptable limits. The altered physiological and biochemical processes that cause decreased plant development are one of the key indicators of heavy metal poisoning. To protect agricultural and human health, as well as save current resources, it is very important to remove heavy metals from polluted soils. Phytoremediation is generally mentioned as one of the best ways to get rid of heavy metals from contaminated soils. Phytoremediation and rhizo filtration methods may get rid of heavy metals and other contaminants in unclean soil and water.

Keyword: Heavy, metal, contamination, agricultural, soil, ground

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Pollutants in the environment include HMs, or heavy metals and metalloids. Because HMs can have a deleterious effect on crop health and production when present in soil at elevated levels, they are also considered agricultural soil pollutants. HMs don't break down easily and can stay in the soil for a long time if plants don't take them up or let them drain out. Many metals, including cadmium, lead, mercury, nickel, copper, and zinc, get into farming grounds and can hurt plants if they are present in large enough amounts. Plants can't handle much pollution as long as they are around Cr, Pb, Hg, Cd, and as which are all very dangerous. Mineral nutrients are important for plant growth and production. There are several types of these nutrients. Some examples are B, Cu, Mn, Ca, Mg, Ni. These elements can improve sugar metabolism, nitrogen fixation, respiration, enzyme activity, gene control, pigment production, photosynthesis, ion homeostasis, and many other cellular processes in plants at low concentrations. Nevertheless, these vital components can have a negative impact on plant development, growth, and reproduction when concentrated at levels higher than what is considered optimal. On the other side, they can also cause plant symptoms of mineral shortage when the concentration drops below specific thresholds. The problem of HM contamination in farmland soils is a worldwide one. Right now, the primary causes of HM pollution in the environment are things like rapid urbanization, more industrial, municipal, agricultural, home, medicinal, and technical uses, as well as specific geological and weather factors. The above factors do play a part, but it's also possible that the problem is made worse in many poor countries by a lack of information about how these substances are bad for both human and animal health. In this study, we only talk about how HMs hurt the health of crops.

Waste Water Irrigation

An estimated 1.0 to 1.5 million hectares (Mha) of land in India is irrigated each year using wastewater (Sengupta 2008). Research in a number of Asian towns has shown that urban vegetable production relies on wastewater irrigation to the tune of half [1] Without understanding the environmental risks, farmers prioritize profit above water quality and use wastewater instead of fresh water. Soils that have been treated with wastewater for a long time might build up heavy metals. Researchers looked at how eating crops and vegetables produced nearby that were watered with wastewater affects people's health. The results showed that all of the vegetables and cereal crops had levels of Cd, Pb, and Ni that were higher than what was allowed by Indian and WHO/FAO standards [2]. Soil contamination and increased heavy metal absorption by crops due to effluent irrigation can have an impact on food quality and safety when heavy metals accumulate excessively in agricultural soils.

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Removal of Untreated Sewage Sludge

Organic materials, nitrogen, phosphorus, and other chemicals necessary for plant development are abundant in sewage sludge. Data issued by the GOI in December 2015 shows that 37% of India's sewage, or 23,277 MLD, is treated, despite the fact that metropolitan areas create an estimated 62,000 MLD of sewage daily. Unfortunately, treatment plants are under operated and poorly maintained, resulting in less than 18,883 MLD of treated sewage. This means that 70% of the sewage is deposited untreated into bodies of water such as rivers, oceans, lakes, and wells Also, a few impoverished nations increasingly employ sewage water for irrigation and solid sludge to make the land more fertile. [3]. On the other hand, sewage sludge is rich in heavy metals, including those that are known to be harmful, such as lead, nickel, cadmium, chromium, copper, mercury, and zinc. Although farmers in sub-urban regions are using untreated sewage to produce crops because of its high nutritional content, the usage of this water for extended durations is a major worry. Heavy metals can be found in sewer sludge because of corrosion in sewage systems, land runoff from towns, and wastewater from homes [4]. Heavy metals have accumulated significantly on farmland in close proximity to a number of Indian cities and towns because to the usage of these wastes in soils.

Heavy Metals Building Up in Plants and Farm Soil Due to Fertilizers

In order to boost plant growth and production and increase soil organic matter, fertilizers give several essential nutrients. Soil fertility is enhanced by fertilizers. Natural fertilizers are known as organic fertilizers, whereas manufactured fertilizers are known as inorganic. Biofertilizers are organic fertilizers made of ammonium compounds like sulfate and nitrate. They are broken down during anaerobic digestion (AD). Inorganic fertilizers are made up of both inorganic and chemical parts. They are also sometimes called chemically created or manmade fertilizers. Heavy metals are made in soil by nutrients, which are made up of both organic and inorganic ingredients. While phosphorus is an important part of many fertilizer mixes, it also adds a lot of heavy metals to the soil when it is applied directly [5]. Phosphate pebbles, which are made when phosphorus fertilizers break down, are very important in the process of metals becoming immobilized in soil by precipitating as metal phosphates. Long-term, excessive fertilizer use leads to heavy metal buildup in farming soils, which in turn lowers soil richness and, by extension, plant growth and production. After a while, it's quite hard to pull heavy metals out of the ground. The ground may store more Cu, Zn, and Cd when pesticides are applied for a long time [6].

What Heavy Metals do to the Health of the Soil

Heavy metals and other wastes made by people from many different actions have mostly ended up in land and water. Heavy metals have become more concentrated in the soil because of human activities like more mining and industry, using too many pesticides and chemicals in farming, watering plants with wastewater, and other similar projects. Heavy metals stay in the environment for a long time after they are released because they are not easily broken down by chemicals or microbes.[7]. Heavy metals can only flow through dirt if their chemical form is easy to get to. Chemical processes in soil that include heavy metals, such as ion exchange, adsorption, complexation, immobilization, and plant absorption, are considered to control how metals are spread out. Heavy metals in the soil have a large effect on both surface and groundwater, making them less healthy. They also change the biological properties of the soil, as well as its color, pH, and porosity. [8. The main ways that heavy metals get into farming grounds are through the use of fertilizers, insecticides, organic manures, wastewater for irrigation, municipal and industrial waste, car emissions, and other human activities.[9]. The majority of pesticides include heavy metals, which end up in soils in significant quantities. Soil arsenate, cadmium, lead, manganese, and zinc contamination is another consequence of using phosphate fertilizers. The addition of pig and poultry manures that have been fed specialized diets can contribute Zn, As, and Cu to soils. It is said that heavy metals can get into the food chain through veggies that are watered with wastewater mixed with chemical fertilizers and pesticides, as well as chicken dung. The farming of toxic metals into the soil has become a major problem for human health, both through direct eating and bioaccumulation in the food chain. These metals also have bad effects on the world as a whole [10]. Researchers have found that metals in the soil can stop plants from growing, storing food, and producing food. This happens by messing up natural processes in plants, like photosynthesis, gas exchange, and nutrient intake. Because of this, crops are more likely to take up heavy metals in agricultural soils with higher levels, which affects the quality of the food. Plants naturally take in heavy metals from the soil via a process called bioaccumulation [11]. Also, when heavy metals are in the soil, organic pollutants can't break down, which implies greater pollution overall. Lead, cadmium, arsenate, zinc, copper, and mercury are just a few of the heavy metals that may be discovered in polluted earth. These contaminants may pile up in living things, make water dirty, and lower agricultural harvests. As a result, these metals can enter into plants through their roots as they pile up in the earth over time. When food has harmful metals in it, it can make the soil less rich and put people's health at risk.

OBJECTIVES OF THE STUDY

1. To investigate heavy metal accumulation in agricultural soil and plants.

2. To investigate the disposal of untreated sewage sludge.

RESEARCH METHOD

Assessing the study area's heavy metal concentrations and comparing them to the criteria set by the Bureau of Indian Standards is vital for determining ground-water appropriateness for various applications [12].

The literature review for this work comes from Research Gate, CeRA, Google Scholar, and other online sources, as well as articles in national and international journals, books, and conference proceedings. The keywords used to write this text were "toxic metals in soil", "toxic metals in plants", "phytoremediation", "phytotoxicity", "rhizofiltration", and "the toxic effects of heavy metals" [13].

Study Area

30.438°N 77.624°E is the coordinates of Paonta Sahib. On average, it's 389 meters (1,276 feet) high. Sitting on the banks of the Yamuna River—which separates Himachal Pradesh and Uttarakhand—it offers a picturesque setting. Located on the borders of Haryana, Uttarakhand, and Western Uttar Pradesh, it is close to the towns of Nahan and Saharanpur. It is also bordering Uttarakhand and Uttar Pradesh. Approximately 44 kilometers from Dehradun, it sits on the westernmost tip of the Doon Valley. Paonta Sahib is 12 miles away from Kalesar National Park. The major town is around 7 km away from Colonel Sher Jung National Park. Hotel Paonta Valley, Hotel Yamuna, and Hotel Guru Surbhi are some of the five-star accommodations available in Paonta Sahib [14].

June 2022 saw the collection of fifteen groundwater samples from various sources, including tubewells, handpumps, and borewells. Fields, homes, and public areas (including schools and gas stations) were the sites of the sample collection. When collecting groundwater samples, the usual protocol was adhered to. After rinsing with HNO3, water samples were collected in clean, 1-liter plastic bottles. Three or four rinses with groundwater were performed on the bottles before to each sample. Water samples were collected from borewells following a 10-minute pumping time. Stabilizing the electrical conductivity and draining any standing groundwater were the goals of this operation. In order to prevent contamination of any type, we wore gloves before handling the sample vials. All of the bottles were appropriately labeled and had tight caps. In order to prevent heavy metal adsorption on the sampling bottle walls, the samples that were collected for analysis were acidified with concentrated hydronium bicarbonate (pH <2). As soon as the water samples were taken, they were put in an icebox and kept at 4°C until they were sent to the lab to be looked at more closely. Using a number of physical properties to analyze.

Toxic Metals in Soil Come From

Toxic metals in the ground come from the soil breaking down over time. There are several known types of it, including as organic molecules, hydroxides, oxides, sulfides, sulfates, phosphates, and silicates. Lead, nickel, cadmium, and mgf3q21qercury are among heavy metals that are utilized a lot. People do a lot of activities that affect and speed up the chemical reactions of metals in soils and groundwater from Paonta Sahib, both in cities and in the country. Heavy metals can build up in these places, which is hazardous for plants and ecosystems [15].

Table 1. Coal ash and several common igneous rocks contain heavy metals.

S. No.	elements (mg kg^{-1})	Rock types		Coal ash	
		Granite	Basalt	Mean coal ash content	Crustal abundance
1.	Cr	8.1	15.01	245	101
2.	Cd	0.012	0.063	12	1.3
3.	Cu	11.6	21.3	216	54
4.	Ni	7.1	17.0	170	74
5.	Pb	29.5	17.0	286	12
6.	Zn	75.6	133.1	571	71

Table 2. Heavy metal concentrations in various inorganic fertilizers and soil additives.

Fertilizers	**Heavy Metals (mg kg^{-1})**										
	Zn	**Cu**	**Fe**	**Mn**	**B**	**Mo**	**Pb**	**Cr**	**Cd**	**As**	**Ni**
Urea (1)	3.1	0.6	35	1.4	2.0	6.4	5.0	6.1	1.0		
Ammonium Nitrate (2)	-	<0.50	-	-	-	-	<0.30	-	<0.10	<0.30[1]	<0.10[1]
Calcium Ammonium Nitrate (1)	8.3	2.8	406	23.6	9.0	55	114	8.0	5.0	-	-
Ammonium Sulphate Nitrate (1)	55.4	0.8	406	54.7	6.4	4	-	-	-	-	-
Ammonium Sulphate (1)	10.2	1.6	25	4.4	6.0	5	-	-	-	-	-
Triple Super Phosphate (1)	417	48.6	3473	76.0	21.4	270	11.2 12.3	87.6	5.0-5.3	16.3-15.3	14.6-26.3
Single Super Phosphate (1)	164	14.4	4051	8902	132	334	485	87	188	-	-
Rock Phosphate (1)	185	31.0	19913	974	71.6	554	961	182	301	16.4-20.3	16.5-50.6
Potassium Chloride (1)	10.1	2.13	101	4.4	15.2	25	-	-	-	-	-
Potassium Sulphate (1)	2.1	8-11	-	2.2-14	3.1	1.1	-	-	-	-	-
Nitro Phosphate 15-15-15 (1)	41	13.0	35	530	143	132	284	53	88	-	-
Nitro Phosphate 10-10-10 (1)	46.4	6.3	4506	121	133	139	-	-	-	-	-
Amm. Phos. Sulp. 10-10-10 (1)	163	9.5	2421	53	241	248	-	-	-	-	-
NPK 12-32-16 (1)	113	16.5	9354	231	208	92.6	-	-	-	-	-
NPK 10-26-26 (1)	37.2	12.2	7753	115.5	177	86	0	0	-	-	-
Diammonium Phosphate (1)	113	8.3	11272	306	397	76.2	197	82	107	-	-
Dairy manure (mean) (2)	-	16	-	-	-	-	7.9	-	0.9	7.0	9.4
Poultry manure (3)	331-454	45-75	-	-	-	-	3.1-8.3	<1.0-7.6	0.10-0.20	-	7.2-9.1
Swine manure (3)	541-1245	255-615	-	-	-	-	7.1-12	2.3-1.4	0.51-0.84	-	10.32

Various Heavy Metal Sources

Over time, using too many pesticides, fungicides, herbicides, and the like affects the soil's basic structure and makes it hazardous for plants to grow in, even though these chemicals are meant to protect crops from pests and disease. Soil microorganisms (bacteria) either don't break down organic pesticides (such DDT, aldrin, benzene hexachloride, etc.) or do so very slowly, which is why they build up in the soil. So, they hurt plant growth a lot, which makes the fruit smaller and less plentiful. The use of more irrigation (which causes salination), fertilizers, herbicides, pesticides, and other farming technologies to boost crop yields has led to soil pollution [16].

Different artificial fertilizers, particularly phosphatic fertilizers, are employed to ensure that crops develop properly in dense agricultural systems. These nutrients may include trace levels of heavy metals (Cd and Pb) due to their lack of purity. If you continue to add too much artificial fertilizer to the soil, it may include a lot more heavy metals [17]. Heavy metal pollution may affect the composition of soil microorganisms, in addition to changing soil characteristics [18].

RESULT AND DISCUSSION

Anthropogenic Sources of Heavy Metals

Heavy metals may seep into urban and agricultural soils from a number of human activities, such as farming, mining, making things, and using synthetic items.[19]. Because of this, heavy metals that come from human activity are even more dangerous than metals that are present in nature. Lead from cars, arsenic, copper, and zinc from smelting, arsenic from pesticides, and nickel, vanadium, mercury, selenium, and other heavy metals from burning fossil fuels are all major human-made causes of toxic metal pollution in the environment. Potential sources of contamination include soils that have been treated with wastewater or municipal sludge in the past, areas near or within mining waste dumps and tailings, industrial sites that have left chemicals on the ground, and areas downwind from these sites [20]. Improperly throwing away chemical waste from different businesses can potentially pollute the soil. Because people have to make a lot of things to meet the demands of a large population, activities like throwing away factory waste, heavy metals, dangerous chemicals, oil, gasoline, and other things are also recognized to be major causes of environmental damage. The key thing that affects how much heavy metal is in the soil is what its parent materials are comprised of. The results indicated that basaltic rocks have more heavy metals than granite rocks. It was also found that coal ash has the mos heavy metals [21].

Soil Amendments and Fertilizers

Putting too much nitrogenous fertilizer on fields makes the soil acidic and pollutes it. In intensive farming systems, soils often get too much or too little fertilizer, which makes it hard to grow crops that need a lot of nitrogen, phosphate, and potassium. The compounds that give these elements contain extremely minor levels of heavy metals like Cd and Pb [22] Also, soil amendments or foliar sprays can add micronutrients to crops to make sure they grow and complete their life cycle correctly. Table 2 illustrates how much heavy metal is in different kinds of fertilizers and soil additives [23].

Pesticides / Herbicides

Synthetic, harmful compounds known as pesticides (DDT, Aldrin, and Dieldrin) eliminate many pests and insects that harm agriculture, but they have several ecological consequences. Sprays that contain copper, including the Bordeaux combination (copper sulphate) and copper oxychloride, are effective against fungus. To keep some parasitic insects at bay, fruit orchards utilized lead arsenate for a long time. Such compounds have been used more selectively, limited to certain locations or crops, as opposed to fertilizers [24]. These compounds will build up in the soil since they are often insoluble in water and do not biodegrade. This means it will cause a wide range of metabolic and physiological problems that impact human health. Na_3 AsO_3 and $NaClO_3$ are two examples of herbicides that can break down in a matter of months [25]. They are also harmful to the environment and have an impact on it. In addition, contrary to what one might expect, research has shown that spraying herbicides actually increases the risk of insect attacks and plant illnesses compared to hand weeding.

Bio-solids and Manures

When bio-solids like animal waste, compost, and sewage sludge are dispersed on the ground, heavy metals including arsenate, cadmium, chromium, copper, lead, mercury, nickel, zinc, and others can build up. People usually use solid or slurried animal feces on crops and pastures [26]. This includes dung from pigs, chickens, and cows. Heavy metals like Cu and Zn are added to pig and chicken feces because they are utilized in their diet and health items. This makes the soil unclean. These animal manures are rich in arsenate, copper, and zinc. If you spread them on small areas of land often, the metals can build up in the soil over time. In municipal solid waste, Table 3 shows the different amounts of heavy metals together with the standards for each one. Bio-solids, which are also called sewage sludge, are the principal organic solid leftovers of wastewater treatment. They are great for recycling [28]. Applying bio-solid materials to soil is a common practice in many countries. This lets urban inhabitants utilize the bio-solids they produce. People usually call in situ sewage sludge bio-solids because they think the term better describes the good things about the substance [29]. The quantity of metals in bio-solids varies on the kind of waste, the kind of company that created it, and how it was cleaned. Sometimes, bio-solids can add metals to the earth, which can subsequently be carried down through the soil and into the groundwater [30].

Table 3. Standards for the amount of heavy metals in municipal solid waste.

Heavy Metals	Solid Waste Municipal	German Standards
	(mg ka^{-1})	
Lead	410	151
Chromium	109	151
Nickel	83	48
Cadmium	3.7	2.1
Mercury	0.6	2.1
Copper	221	151
Zinc	918	490

Chemical Composition of Groundwater

There are many natural and man-made things that can change the chemicals in groundwater, which in turn changes the quality of groundwater. Groundwater quality is affected by the minerals, salts, and trace elements that come from rocks, dirt, and natural layers and get into the water. Animal dumping, farming, and industry are some of the things that people do that can harm groundwater with heavy metals, pesticides, and chemical compounds. Physicochemical features are very important for finding possible threats to human health and the environment because they show how clean the water is and can help us understand where different chemicals and dangerous substances in groundwater come from and how they behave. There was no turbidity, smell, or color in the groundwater samples. We looked for heavy metals including iron, lead, chromium, and cadmium, as well as chemical and physical parameters like temperature, total dissolved solids, salt, and electrical conductivity. Calcium, magnesium, and phosphate were some of the chemical contributors. The WHO and the [31] have regulations for how clean drinking water should be. Table 4 shows them to you.

Physical Parameters

Odor: All groundwater samples demonstrated no odor, in accordance with the BIS drinking guidelines.

pH: The pH of the water in the region where the investigation took place ranged from 6.30 to 7.40, which shows that the sample locations were spaced apart. The pH of the water samples was between 6.5 to 8.5, which is what the World Health Organization states is safe. The only exceptions were sites 2(6.35), 9(6.30), and 10. Most of the water samples had a pH below 7, which suggests the water is a little acidic.

Temperature: Water samples taken from the research region had temperatures ranging from 27.7°C at the lowest to 36.6°C at the highest. How well water treatment units work is highly dependent on the water's temperature. It is possible that solids in water might settle less quickly when the water's viscosity rises at lower temperatures. This is because high viscosity makes particle settling more difficult. This makes it less efficient for the settling unit to clean water for solids. Furthermore, filtration units may experience increased resistance due to excessive viscosity, leading to a decrease in pressure. This slows down the flow of water through filters, which makes filters less effective at getting rid of pollution [32].

Electrical Conductivity: There is a close connection between how much charged compounds are in water and how well it conducts electricity. A substance's electrical conductivity tells you how well it can transmit an electric current. Some things that can influence the number of ions in water include temperature, organic matter, and total dissolved solids (TDS). These things influence how easily electricity can flow through water. The electrical conductivity was measured between 640 and 5110 µScm-1. The findings indicated that all of the EC values are greater than what is recommended, based on the BIS value of 301 µScm-1 [32]. The high EC in groundwater demonstrates that water travels around, cations trade, surfaces become wet, and other things happen.

Table 4. Table delineating the standards for potable water.

Parameters	Standard WHO	Standard Indian	Guidelines EPA
Color		6-11 Hazen units	
Odor	Unobjectionable	Unobjectionable	
Temperature. (°C)			
pH	6.4-8.4	6.5-8.5, 6.5-9.5	6.5-9.5
Electrical Conductivity (µS/cm)	301us/cm	301us/cm	2501us/cm
Total Dissolved Solids (mg/L)	501-1001	501-1001	
Total Hardness (mg/L)		201-601	
Salinity (mg/L)		>1198	
Chlorides (mg/L)	201-601 mg/l	251-1011 mg/L	251 mg/L
Calcium (mg/L)		69-198 mg/L	
Cadmium (mg/L)		1.002 mg/L	
Chromium (mg/L)		1.04 mg/L	
Lead (mg/L)		1.03 mg/L	
Iron (mg/L)		1.2 mg/L	

Total Dissolved Solids: People typically use total dissolved solids (TDS) levels to illustrate that water is dirty. There is a significant connection between changes in electrical conductivity and TDS levels [33]. The amount of Total Dissolved Solids (TDS) at all sample locations varied from 455 to 3,630 mgl-1, with site 15 having the highest amounts. The World Health Organization (2004) advises that drinking water should not have more than 500 mg/l of total dissolved solids (TDS) [34].

Total Hardness: Aquifer ion exchange and the breakdown of calcareous rocks lead to groundwater with a high TH. While high TH levels pose no threat to human health when ingested in moderation, they can disrupt water distribution systems. Boilers used for industrial purposes are susceptible to corrosion, and long-term usage in agriculture irrigation can degrade soil quality. According to the BIS guideline, 200 mg/l is the permitted level for TH. A TH level over the permissible limit was detected in all but one of the samples. From 200 mg/l at the lowest to 548 mg/l at the highest concentration, readings were taken.

Salinity: The salinity ranges from 328 mg/l (the least) to 7090 mg/l (the maximum) in various groundwater locations. For potable water, a salinity level of more than 1200 mgl-1 is considered unsafe. The concentration of elements including sodium, fluoride, sulphate, boron, and arsenic is inversely proportional to groundwater salinity.

Chemical Parameters

Chloride: We saw that chlorine naturally occurs in groundwater in different levels. According to BIS (2012), the amount of chlorine that is safe to consume is between 250 and 1000 mg/L. The study found that the levels of chloride in the region ranged from 39 to 369 mg/l. The sources, such agricultural runoff, industrial and sewage effluents, and others, also add to the problem through infiltration [35]. Some samples are below the BIS limit for drinking water, but most are far within it. The high levels of chlorides in groundwater might be because sewage and industrial waste are mixed together, which releases a lot of metal and organic ions.

Calcium: According to [36] 75 mg/l of calcium is the optimal level for drinking water. Calcium concentrations in water ranged from 12.82 mg/l at the lowest end to 105.8 mg/l at the highest. Most of the groundwater tests had amounts of Ca2+ that were safe for people to drink. One important reason for Ca^{2+} in groundwater is that calcium-rich rocks in the aquifer break down. Groundwater Ca^{2+} ion concentrations can decrease due to changes in parameters like temperature and pressure, even though calcium compounds are normally stable in water Because of its high Ca2+ and Mg2+ concentrations, groundwater is not always suitable for irrigation because of its hardness.

Cadmium: Cadmium is frequently thought of as an anthropogenic element because it is used in so many industries and is found in nature because of so many human activities. BIS regulations say that the most cadmium that is safe to have is 0.003 mg/l. The majority of the water samples exhibit cadmium concentrations within the detectable limit (BDL), with the exception of three samples that display amounts exceeding the BDL (0.037 mg/l) and falling below the minimum detectable concentration (beyond detection). This doesn't have a big effect on groundwater.

Chromium: Natural sources of chromium include rocks, plants, dirt, and volcanic dust. However, human actions like the release of waste water from the steel and pulp industries and the wear away of Cr^{3+} deposits in natural water sources are examples of manmade sources of Cr^{6+} in drinking water [37]. Chromium is a vital metal that finds application in a wide range of industries and consumer goods Besides being able to stop corrosion, chromium is used to make alloys, paints that stop rust, wood preservatives, dye fixatives, and cooking systems and stoves [38]. Chromium levels should not exceed 0.05 mg/l, according to the BIS. Although no chromium was discovered in the other samples, two of them had levels that were too high [39].

Iron: Iron makes groundwater change color, and when there is a lot of it, the water tastes harsh and astringent. Iron pollution may cause several problems, such changing the color of clothes and building up on supply pipes [40]. In the research region, iron levels ranged from BDL to 1.727 mg/l. The test findings indicated that BIS's rules were not followed by three of the samples. The other samples contained quantities that were less than what was authorized.

Fundamental Heavy Metal Chemistry

Polluted earth can slow down crop development because heavy metals can build up in food chains [43]. If you know a little bit about chemistry, you can better grasp how accessible certain heavy metals are and how to clear them up in soil. This is because the chemical form of the metals has a huge effect on what happens to them and how they react with soil (Table 7). Heavy metals bind to soil particles, which changes their chemical structure such that they are bioavailable, mobile, and hazardous in different ways.

Table 5. Table displaying groundwater physical parameters and comparison with the [41] drinking water standard.

S. no.	Parameters	Acceptable Limit [41]	Permissible Limit [41]	Minimum	Maximum	Average	% of samples exceeding Acceptable limit(x)	% of samples exceeding Permissible limit(y)
1	Odor	Unobjectionable	Unobjectionable	Odorless	Odorless	-	-	-
2	pH	6.5-8.5	-	5.31	7.28	6.82	19(2)	-
3	Temp.(°C)	-	-	28.8	35.3	-	-	-
4	EC(µScm-1)	301	-	638	5112	2005.13	100(15)	-
5	TDS (mg/l)	500	1992	454	3638	2156.23	98.2 (13)	18 (2)
6	T Hardness (mg/l)	201	601	200	543	341.64	94.2(13)	-
7	Salinity (mg/l)	-	1201	325	7098	1442.65	-	35.33 (5)

Table 6. A table that compares the groundwater's chemical parameters to the water standards [42].

S. No.	Parameters	Acceptable limit [42]	Permissible limit [42]	Minimum	Maximum	% of samples exceeding Acceptable limit (x)	% of samples exceeding Permissible limit (y)
1	Chloride (mg/l)	250	1000	39	369	20 (3)	0 (0)
2	Calcium (mg/l)	75	200	12.6	105.7	6.5 (1)	0 (0)
3	Cadmium (mg/l)	0.002	No any relaxation	BDL	1.037	18 (3)	
4	Chromium (mg/l)	0.04	No any relaxation	BDL	1.057	12.4 (1)	
5	Lead (mg/l)	0.02	No any relaxation	1.15	1.91	98 (14)	
6	Nickel (mg/l)	1.03	No any relaxation	BDL	1.042	19 (2)	
7	Iron (mg/l)	1.4	No any relaxation	BDL	1.73	20 (2)	

Heavy Metal Toxicity's Effect on Plants

The way plants absorb in different heavy metals from soil or those that breakdown easily in root fluids. Plants also needed certain heavy metals to grow and thrive, however soils that have too much of these metals are bad for plants [44]. Also, when the levels of heavy metals in plants are too high, they might slow down plant growth. The degree of harm that heavy metals inflict on plant growth is contingent upon the particular heavy metal involved [45]. Table 6 gives an overview of the evidence that indicates how particular metals can hurt the growth, biology, and physiology of different types of plants.

Nickel

It has long been recognized that Ni has phytotoxic effects. In addition to a decline in growth rate, signs of Ni poisoning may manifest as chlorosis, slowed root development, brown interval necrosis, and other symptoms that are species-specific. Plant toxicity was indicative of Ni concentrations between 50 and 100 mg/l (dry weight basis). In this case, spring wheat showed signs of being poisonous at 8 mg kg-1, but oats didn't lose any output. factors because of a drop in photosynthesis, plant feeding with minerals, and the way some enzymes work [46].

Table 7. The fundamental chemistry of heavy metals.

S. No.	Heavy Metals	Chemistry of Heavy metals				
		Atomic Number	Atomic Weight	Density (g cm^{-3})	Melting Point (ºC)	Boiling Point (ºC)
1.	Chromium	21.1	51.1	8.18	1874.1	2663.0
2.	Nickel	22.1	57.3	9.80	1452.1	2912.0
3.	Copper	25.1	62.4	7.93	1082.1	2594.0
4.	Zinc	31.1	63.5	8.13	418.4	907.0
5.	Arsenic	32.1	74.1	6.69	816.1	613.0
6.	Mercury	81.1	199.7	14.5	–35.7	356.0
7.	Cadmium	44.1	113.5	7.66	318.8	764.1
8.	Lead	81.1	205.3	10.30	322.5	1724.1

Lead

Root stunting, chlorosis, and a quick suppression of root development are the visible, non-specific indicators of lead poisoning. Because of Pb phytotoxicity, enzyme activity are inhibited, mineral nutrition is affected, and water balance is upset. These diseases interfere with the plant's regular physiological processes. Cell death might occur at high amounts of Pb. Lead levels that are too high stop seeds from sprouting and slow the growth of young plants. Soil lead slows down seedling growth, root and shoot expansion, and root and shoot dry mass. Germination of rice seeds was lowered by 14 to 30% and seedling development was reduced by 13 to 45% when Pb concentrations were high [47].

Arsenic

The development of plants is stunted when their arsenic level is high because it hinders metabolic processes like photosynthesis. Forty milligrams per kilogram was determined to be the hazardous threshold for agricultural plants. Hence, biomass output and agricultural yields are drastically reduced by greater arsenic concentrations. Few factors contribute to the low levels of arsenate in plants' edible parts [48] These include (i) the soil's poor bioavailability of arsenate, (ii) roots' limited ability to absorb arsenate, (iii) shoots can't move arsenate from roots to as easily as they could in roots; and (iv) plants die quickly when arsenate levels are low in their tissues. Most plants are dangerous to people and other animals even in very small amounts. Most of the time, soil pollution leads to stunted growth and lost crops [49].

Cadmium

The major ways that soils are polluted with cadmium are through bio-solids, phosphate fertilizer, and waste water from businesses that use and recycle cadmium. Cd showed bad impacts on floral output and pollen germination when tested in vitro. It also prevented the growth of pods and seeds, sped up the growth of tubes, and reduced the quantity of ovules and pistils, even if the ovules themselves were normal and sensitive. Cadmium treatment increased the protein content in seeds that were physiologically mature. When Alfisol and Ultisol were exposed to Cd-enriched sewage sludge/city compost, their yields dropped a lot. We got back less Cd (8.3% in the leachates) because most of the Cd that was put on the soil remained in the top 10 cm (87–96%) [50].

Effects of Soil Toxicity from Heavy Metals

Toxic effects on soil bacteria show up as changes in population growth, bio-diversity, and a lot of other things [51]. Heavy metals are harmful and get into the food chain, so their presence in soils is bad for ecosystems all over the world [52]. Heavy metals are dangerous to ecosystems in many ways, including to people, animals, and plants. Ingesting it directly, having it absorbed by plants or animals, drinking polluted water, or changing the soil's pH, porosity, color, or natural chemistry are all ways that contaminants can affect soil quality.

The effect of metals on the biochemical and biological properties of soil is very reliant. Heavy metals have an indirect influence on soil enzymatic activity because they change the makeup of the bacteria that make enzymes. Heavy metals can damage soil biota by lowering the quantity and activity of soil microbes and getting in the way of critical microbial activities. Different metals change how enzymes work in soil in different ways [53]. This is due to the fact that various enzymes in soil have distinct chemical affinities, and heavy metals exert varying influences on each enzyme. In general, urease activity was slowed down in this order:

Cr > Cd > Zn > Mn > Pb [54]. The kinds of plants that flourish in an area and how active and diverse the microorganisms are good markers of how good the soil is. Microorganisms are necessary for recycling nutrients, maintaining soil structure, eliminating toxic compounds, and regulating insect populations [55].

Long-term use of Artificial Fertilizer and the Buildup of Heavy Metals in Vertisols [1]

Over time, using different kinds of agricultural inputs (like inorganic fertilizers and organic manures) on the soil caused a lot of dangerous and necessary heavy metals to build up. These metals include zinc, iron, manganese, copper (Cu), and lead (Cd). Table 5 of the long-term fertilizer experiment with soybean-wheat cropping sequence in a Vertisols [56] shows this. The treatment that obtained the super-optimum dose of fertilizers (150% NPK through urea, SSP, and MOP, respectively.

The Amount of Heavy Metals that Should not be in Earth, Water, or Plants

When plants and farming soil get too much heavy metals from different forms of soil pollution, the soil can become less healthy and less safe for people. Table 5 shows these restrictions together with the basic norms for Europe [57].

Standard for Compost Manure Solid Waste

Table 6 displays the rules imposed by the Central Pollution Control Board, the Management and Handling Rules 2000, the MEF, and the most quantity of heavy metals that can be in compost manure solid waste [58].

Table 8. Impact of various therapies on necessary and dangerous heavy metals.

Treatments	**Heavy metals that are dangerous ($mg\ kg^{-1}$)**			
	Cd	**Pb**	**Ni**	**Cr**
50% NPK	1.032	0.734	1.356	1.133
100% NPK	1.034	0.809	1.386	1.157
150% NPK	1.041	0.883	1.404	1.181
100% NP	1.025	0.631	1.321	1.053
100% N	1.021	0.762	1.513	1.142
100% NPK + FYM	1.017	0.592	1.295	Detect
100% NPK – S	1.016	0.743	1.326	.045
Control	1.014	0.424	1.195	Detect
CD (*P = 0.05*)	**0.02**	**0.16**	**0.04**	**0.02**
Treatments	**Important amounts of heavy metals ($mg\ kg^{-1}$)**			
	Zn	**Fe**	**Mn**	**Cu**
50% NPK	1.47	21.66	16.21	0.56
100% NPK	1.46	22.82	18.90	0.41
150% NPK	1.72	25.04	17.84	0.63
100% NP	1.52	27.72	18.64	0.41
100% N	1.50	18.72	11.53	0.21
100% NPK + FYM	1.92	32.03	15.55	0.83
100% NPK – S	1.44	25.88	16.00	0.31
Control	1.45	16.03	13.18	0.17
CD (*P = 0.05*)	1.08	3.31	2.60	1.17

Table 9. Standards for heavy metals in solid waste from compost manure.

Heavy Metals	The highest quantity that is safe (mg kg^{-1})
Zinc	1010
Copper	301
Nickel	52
Cadmium	4.5
Chromium	41
Lead	102
Arsenic	9
Mercury	1.13

Getting Rid of Polluted Grounds

"Remediate" means to clean up bad soils, and "phytoremediation" involves employing plants or parts of plants to solve environmental problems like dirty soils or polluted groundwater. Depending on how the unclean soil is cleaned up, the amount of different heavy metals might alter a lot [59]. We need to know what sort of heavy metal waste is in the soil, how much of it there is, and where it is. After the location has been described, the following step is to figure out how much of each metal should be in the earth. There are numerous techniques to get rid of metals that have gotten into the soil [60].

Phytoremediation as a Means of Absorbing Heavy Metals

Over the last ten years, a lot of people have been interested in creating plant-based cleanup solutions that work, don't cost too much, and are beneficial for the environment [61]. Phytoremediation is the use of different kinds of plants to get rid of, transport, stabilize, and eliminate contaminants in soil and water. The main purpose of phytoremediation is to get rid of heavy metals and other biological contaminants that are bad for the environment. People reported that plants were utilized to clean up dirty water more than 300 years ago. People prefer this technology since it doesn't cost much and doesn't affect the environment. Hyper-accumulators are very good at getting rid of heavy metals when it comes to phytoremediation. Genetic engineering is also helping to improve phytoremediation. Certain chemicals that make heavy metals more mobile in soils can help phytoremediation work considerably better. Plants can then absorb more of these metals. The following outlines many mechanisms that underpin this: Phytoaccumulation, phytoextraction, phytodegradation, phytovolatilization, and so on.

Phyto-stabilization

Using plant roots for Phyto stabilization can lower the movement and absorption of pollutants in the soil. Its main job is to clean up dirt, silt, and sludges. It's also called "in-place inactivation." In this case, pollution in the soil are either stopped by chemicals made by the plant's roots, taken up by and kept by the roots, or gathered in the rhizosphere. This approach helps get rid of Cr, Cu, As, Cd, Pb, and Zn by making it difficult for toxins to move around. This stops them from getting into the groundwater. A greenhouse experiment on Phyto stabilization by [62] showed that higher concentrations of heavy metals (40 and 50 ppm) hindered the development of sorghum plants, whereas lower concentrations (5 to 20 ppm) encouraged shoot growth and enhanced plant biomass. The roots of the sorghum plant were also the principal method that heavy metals got into the plant at all test levels (5, 10, 20, 40, and 50 ppm).

Phyto-extraction

The plant's roots take in the water and nutrients as well as the contaminants in this situation. Phytoextraction is a way to clean up the environment by putting contaminants in portions of plants that grow above ground. Phytoaccumulation is another name for this process. Plants' roots let in harmful things, which are subsequently kept in their stems and leaves. Hyperaccumulators are plants that can store a lot more heavy metals in their shoots than is common for soil or other plants that don't accumulate metals. The contamination in the area is gone once the plants are plucked, although it may not be all gone [63] claims that cleaning up soil with phytoextraction would cost roughly 10 times less per acre than current methods.

Phyto-stabilization

Using particular types of plants to clean up toxic metal contamination in soil and groundwater by allowing the plants take up and store the metals. If these pollutants adhere to the roots or rain falls on them in the root zone, they can't flow through the soil or be carried away by erosion and deflation [64].

Phyto-volatilization

Plants take in unclean water and then let the harmful chemicals out into the air through their leaves. Plants may absorb poisons from the ground through their roots and foliage. They are then turned into volatile compounds and sent out into the air by evaporation. Phyto-volatilization is the greatest approach to get rid of things like mercury metal most of the time. In laboratory experiments, tobacco (N. tabacum) and a genetically engineered model plant (Arabidopsis thaliana) were employed a less hazardous form, which was subsequently released into the atmosphere. It’s really vital to understand more about the problem of toxic metal contamination right now, especially in farming soils, which are highly crucial for the bioaccumulation of metals in plants and other foods [65].

Rhizofiltration

The process of purifying polluted water by use of plant roots in order to eliminate heavy metal pollutants. Synonyms for "rhizofiltration" include "adsorption" and "precipitation." This is how artificial wetlands clean up municipal wastewater: pollutants in the water around the roots of plants take them up and store them in their roots. Electron microscopy and histochemical studies showed that there were a lot of Pb deposits at the tips of the roots of maize plants.

Phytodegradation

Plants and bacteria that live in the soil may break down organic contaminants. After the roots take in the contaminants, the plant can either store them or break them down. Plants can also help clean up contaminated regions by putting enzymes into the soil. One probable way for many contaminants to get into the root, where they might break down, is by passive absorption through the root's cell walls' micro-pores.

Hyperaccumulation

When plants can take in heavy metals even when the concentration of the metals in the ground is lower than the concentration in the cell cytoplasm, they are called hyperaccumulators. Because of this, they can store a lot of metals in their cells and yet execute their metabolic and development processes properly.

DISCUSSION

Heavy metal poisoning in rural soil and groundwater is a big hazard for the health of people and the environment. This is due to rapid growth, intensive farming, and poor waste management. Heavy metals including cadmium, lead, arsenic, mercury, chromium, and nickel may enter into farm soils from chemical fertilizers, herbicides, sewage sludge, mining, and watering crops with dirty groundwater. These metals can then be stored in the soil for a long time. Since these metals don't break down, they have a bad effect on the physicochemical properties of the soil, the activity of microbes, the availability of nutrients, and food growth. Heavy metals can seep downhill through different types of soil based on their pH, organic matter content, and redox conditions. This is made worse when they mix with dirty groundwater. The likelihood of groundwater pollution is increased in sandy soils that contain less organic matter because these soils allow for greater mobility of metals. Soil acidity increases metal solubility, which in turn increases the likelihood of leaching and plant absorption. An ongoing cycle of pollution worsens accumulation in the soil-plant system when polluted groundwater used for irrigation reintroduces heavy metals into agricultural soils. Heavy metal pollution is bad for ecosystem health and organic processes in the soil. Soil fertility is reduced when metal concentrations are high because these metals limit the activity of beneficial microbes, enzymatic activities, and nutrient cycling. Groundwater is the principal water supply in many rural agricultural areas, however heavy metal contamination lowers water quality for human use and drives up treatment costs. Remediation operations are already complicated due to metals' lengthy half-life, therefore integrated management solutions are necessary.

The debate as a whole emphasizes the necessity for long-term mitigation strategies by demonstrating the interrelatedness of contaminated agricultural soil and groundwater. To lower the amount of heavy metals that can move around and be absorbed by living things, it is important to keep an eye on things, use agrochemicals carefully, water plants safely, and use cleanup methods like phytoremediation and soil amendments. Heavy metal pollution in farming systems needs to be fixed right away to protect human and natural health, keep groundwater resources safe, and make sure there is enough food for everyone [66].

Phytoremediation is a long-term, sustainable solution that employs plants to clean up polluted areas by removing, stabilizing, or degrading pollutants, especially heavy metals. Because it uses so little energy and equipment, it is far more cost-effective than traditional physicochemical cleanup approaches. To further prepare the land for agricultural use in the future, phytoremediation enhances soil structure, fertility, and microbial activity. Since it doesn't disrupt the soil profile during rehabilitation, it's both visually beautiful and ecologically benign. Additionally, some plants may be able to store heavy metals in a way that is harmful to both people and the environment. Cadmium, lead, and arsenic are some of these.

Phytoremediation does have certain restrictions, though, so it isn't without its advantages. Sites necessitating quick cleanup should not be considered since the procedure is often sluggish and may want several growing seasons to get acceptable pollution levels [67] Soil characteristics, weather, and plant development all play a role in how successful it is, which is depth-dependent relative to the root zone. Heavy metal toxicity at high concentrations can decrease biomass and remediation effectiveness. Not adequately managing the disposal of polluted plant biomass also creates a secondary environmental danger. Another limitation of phytoremediation is its limited effectiveness in treating very polluted soils and toxins that plants have a hard time up taking or converting.

CONCLUSION

Heavy metal ions polluting our world is the most important problem we face today on a global level. More and more people are living in cities and factories, which is driving this trend. Most toxins and pollutants eventually sink to the ground through soil. When people do things that release heavy metal ions into the world, they pollute water and land on a large scale. These toxins, which stop microbial activity, are what make the soil less healthy. One sign of heavy metal poisoning is that plants don't grow as well because their physiological and biological processes have changed. Getting rid of heavy metals from dirty soils is important to protect current resources and lower risks to human health and crop yield. Here, phytoremediation technique is often cited as one of the top options for removing toxic metals from polluted soils. Phytoremediation and rhizo filtration are two ways to clean up contaminated soil and water by getting rid of heavy metals and other harmful substances. This means that the technology is healthy for the environment and can help you save money. Researchers looked at the groundwater in Bathinda and found that the water table is particularly filthy with heavy metals, total dissolved solids (TDS), and total hardness (TH). This water is not safe for people to drink because it doesn't dissolve oxygen well and has a lot of TDS in it. The study makes it clear that heavy metals pollute the groundwater all the time. The worrisome levels of lead and iron in Paonta sahib's groundwater mean that the problem needs to be fixed right away. According to the results, the presence of several chemical species makes groundwater less healthy. It is very important to quickly switch to growing methods that are better for the earth, people's health, and food security. Groundwater in the Bathinda area is usually not safe for people to drink, which shows how important it is to find good ways to remove dangerous chemicals from it.

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