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AN ANALYTICAL STUDY OF HEAVY METALS CONTAMINATION IN WATER: CASE STUDY OF MAHENDRAGARH DISTRICT, HARYANA

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Abstract

This study explores the contamination of groundwater by heavy metals in Mahendragarh district, Haryana, focusing on lead (Pb), cadmium (Cd), chromium (Cr), and copper (Cu). Water samples were analyzed using Inductively Coupled Plasma Mass Spectrometry (ICP-MS) and Atomic Absorption Spectroscopy (AAS) to quantify metal concentrations. The research also examines the potential of activated carbon derived from local tree leaves to remove these contaminants. Results indicate that activated carbon significantly reduces heavy metal levels, with up to 85% removal efficiency for lead and copper, and 70% for cadmium and chromium. The findings highlight the critical issue of water contamination by toxic metals in Mahendragarh, emphasizing the health risks, including neurological disorders and cancer, associated with prolonged exposure to contaminated water. The study proposes sustainable and affordable solutions, such as activated carbon, to mitigate heavy metal pollution in rural areas. Immediate interventions and policy reforms are essential to safeguard public health and ensure safe drinking water.

Keywords: Groundwater, Heavy Metals, Lead, Cadmium, Chromium, Copper, Activated Carbon, Water Pollution

1. Introduction

Water is an indispensable resource for human survival, agricultural production, and industrial development. It constitutes nearly 70% of the Earth's surface, with groundwater representing a significant portion of freshwater reserves. According to the World Health Organization (WHO), approximately 230 million people around the globe spend over 30 minutes per day collecting water (WHO, 2021). This alarming figure underscores the global challenge of water scarcity and access to safe drinking water. While water is a renewable resource, it is not evenly distributed across the globe, and contamination from a variety of pollutants has become a serious issue that directly impacts human health, food security, and ecosystem stability. One of the most significant environmental threats to water quality today is heavy metal contamination. These toxic metals, which include lead (Pb), cadmium (Cd), chromium (Cr), and copper (Cu), are ubiquitous in both natural and anthropogenic environments. Their presence in water can result from several sources, including industrial effluents, agricultural runoff, and mining operations (Gopalakrishnan et al., 2012). Heavy metals are often persistent in the environment due to their low biodegradability, and once they enter the water system, they pose substantial risks to both aquatic life and human health. The impact on public health can be profound, ranging from neurological disorders, renal dysfunction, and cancer, to other chronic diseases caused by prolonged exposure to contaminated water.

In India, the issue of water contamination is widespread, and the state of Haryana, particularly Mahendragarh district, is no exception. Mahendragarh, located in the southern part of Haryana, is primarily reliant on groundwater sources for both drinking and irrigation. Over the past few decades, rapid urbanization, industrialization, and agricultural expansion have exacerbated the pollution of water resources in the region. As per studies conducted in various parts of India (e.g., Jha, 2010), areas such as Mahendragarh are vulnerable to high levels of fluoride, heavy metals, and other pollutants, which severely degrade the quality of water, making it unfit for consumption. Heavy metal contamination in groundwater is particularly concerning, as these metals accumulate over time and pose serious health risks. The World Health Organization sets permissible limits for several heavy metals in drinking water, such as lead (0.01 mg/L), cadmium (0.003 mg/L), and chromium (0.05 mg/L), but many regions, including Mahendragarh, report concentrations exceeding these limits (Gopalakrishnan et al., 2012). Furthermore, fluoride contamination, often found in conjunction with heavy metals in groundwater, is also a major public health concern in areas with high geological fluoride concentrations. Fluoride in excessive amounts leads to dental and skeletal fluorosis, which causes the weakening of bones and teeth, resulting in physical disabilities (Kumar & Saxena, 2011).

The introduction of industrial pollutants and poor waste management systems has exacerbated the contamination levels in both surface and groundwater sources. In Mahendragarh, heavy metal pollution often stems from nearby industries, such as cement factories, electroplating units, and pharmaceutical plants, which discharge untreated wastewater into rivers and groundwater sources. These industrial effluents often contain metals like lead, cadmium, chromium, and zinc, which can be toxic to both humans and wildlife. Agricultural runoff, rich in pesticides and fertilizers, further contributes to the problem by introducing harmful substances like nitrates, phosphates, and various heavy metals into water bodies, exacerbating water quality degradation (Ashley & Burley, 2017). The adverse impacts of heavy metal contamination in water have been studied globally. For instance, Apambire et al. (2015) reported high levels of fluoride in the water in northern Ghana, where fluoride concentrations reached up to 4.00 mg/L, leading to widespread dental fluorosis among the population. Similarly, in Tirunelveli district in Tamil Nadu, India, Gopalakrishnan et al. (2012) identified water sources with fluoride levels exceeding the WHO limits, resulting in endemic fluorosis in several villages. These findings are in line with research conducted in Haryana, which revealed that certain regions, including Mahendragarh, face the dual challenge of fluoride and heavy metal contamination in groundwater. Jha (2010) specifically observed that fluoride concentrations in six different locations in Mahendragarh exceeded 1.5 mg/L, with some samples showing levels as high as 3 mg/L, a figure well beyond the permissible limit. Given the risks associated with drinking water contaminated by heavy metals, it is imperative to explore cost-effective and sustainable methods to remediate contaminated water in areas like Mahendragarh. Activated carbon is one of the most promising materials for water purification due to its high surface area and adsorption capacity (Boyle & Chagnon, 2018). Activated carbon is capable of removing a variety of contaminants, including heavy metals, from water. This makes it an effective solution for treating contaminated water, especially in regions like Mahendragarh, where conventional water treatment systems may not be readily available or affordable. The use of locally available materials, such as tree leaves, for activated carbon preparation presents an affordable and eco-friendly alternative for water purification (Gopalakrishnan et al., 2012). The development of activated carbon from indigenous medicinal plants like Brassica Juncea and Helianthus Annus, treated with sulfuric acid, can provide a viable solution for removing harmful metals such as Pb2+, Cd2+, Cu2+, and Cr3+ from contaminated water sources.

Activated carbon adsorption works by physically adsorbing heavy metals onto its surface due to its large pore volume and surface area. The surface functional groups present on activated carbon play a key role in the adsorption process. Functional groups such as carboxyl, hydroxyl, and amine groups interact with metal ions, allowing activated carbon to effectively remove them from water. This process can be enhanced through the optimization of conditions such as pH, contact time, and adsorbent dose (Boyle & Chagnon, 2018).

Following are the Objectives of the Study

1. To measure the levels of **lead (Pb)**, **cadmium (Cd)**, **chromium (Cr)**, and **copper (Cu)** in groundwater samples from Mahendragarh.

2. To prepare **activated carbon** from **locally available tree leaves** and assess its effectiveness in removing heavy metals from contaminated water.

3. To evaluate the health risks posed by heavy metal contamination in drinking water.

4. To propose recommendations for improving water quality in the district.

The district of Mahendragarh faces severe challenges related to water contamination, particularly due to the presence of harmful heavy metals. These metals can accumulate in the human body over time, leading to chronic health problems. The high fluoride levels in groundwater further complicate the issue, contributing to **fluorosis** and other related health disorders. This research aims to evaluate the contamination levels of heavy metals and propose cost-effective solutions to treat the contaminated water.

2. Review of Literature

2.1. Heavy Metal Contamination in Water Bodies

Heavy metal contamination in water bodies has been a significant concern globally, with many studies identifying the presence of toxic metals like lead (Pb), cadmium (Cd), and chromium (Cr) in surface and groundwater. According to Gopalakrishnan et al. (2012), heavy metals enter aquatic systems through various anthropogenic activities such as

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industrial discharges, mining, and agricultural runoff. These metals are highly toxic and tend to accumulate in the environment, posing a threat to both aquatic life and human health. Behera et al. (2014) explored heavy metal contamination in groundwater across West Bengal, India, revealing alarming levels of zinc and cadmium in areas close to industrial zones. They found that certain water bodies in the Purulia district contained concentrations of metals that exceeded WHO permissible limits, posing serious health risks. Similarly, in the Tungabhadra Basin, Karnataka, Jha (2010) noted that chromium and cadmium levels were significantly high in local groundwater, raising concerns about the contamination of drinking water. Furthermore, Apambire et al. (2015) conducted a study on the Bolgatanga region in Ghana, where they observed high fluoride and lead concentrations in groundwater, which directly contributed to dental fluorosis and other health problems among residents. These studies indicate that water sources across different parts of the world are increasingly contaminated with harmful heavy metals due to industrialization and lack of effective water management systems. Regular monitoring and remediation are critical to address the problem of heavy metal pollution in water.

2.2. Fluoride Contamination and Its Health Impacts

Fluoride contamination in drinking water has been a serious issue in several countries, especially in regions where fluoride-containing minerals are naturally present in geological formations. Nanyaro et al. (2015) reported high fluoride concentrations in water in regions around the East African Rift Valley, primarily caused by volcanic activity. They found that these regions had significantly higher fluoride concentrations, reaching up to 4.5 mg/L, which led to a rise in fluorosis cases, particularly affecting the teeth and bones. Similarly, Ashley & Burley (2017) reviewed global studies on fluoride contamination, noting that regions like Delhi have fluoride levels in drinking water exceeding the WHO's recommended limit of 1.5 mg/L. They concluded that long-term exposure to high fluoride levels causes both dental and skeletal fluorosis, making it a pressing issue in urban areas with over-extraction of groundwater. Kumar & Saxena (2011) highlighted the problem of fluoride contamination in Uttar Pradesh, where high fluoride levels were found in hand-pump water across multiple villages. They noted that the fluorosis prevalence was especially high in areas with deep borewells, which accessed groundwater rich in naturally occurring fluoride. Susheela et al. (2018) further confirmed that fluoride levels in areas like North West Delhi were particularly high, with concentrations exceeding 4 mg/L in some areas, causing significant health impacts like gastrointestinal discomfort and skeletal deformities. These studies underscore the importance of regular water quality monitoring and the need for defluoridation measures in areas affected by high fluoride levels.

2.3. Strategies for Heavy Metal Removal from Water

Several studies have investigated remediation techniques to reduce heavy metal contamination in water, with a focus on adsorption methods using materials like activated carbon. Boyle & Chagnon (2018) reviewed the use of aquatic plants in heavy metal remediation and highlighted the effectiveness of activated carbon as an adsorbent for pollutants like lead and cadmium. Activated carbon, with its high surface area and porosity, has been shown to be an effective material for removing toxic metals from water. Kumar & Saxena (2013) emphasized the potential of using activated carbon derived from agricultural waste and biomass for heavy metal removal, particularly in rural areas where access to expensive water treatment technologies is limited. They found that activated carbon prepared from agricultural waste such as coconut shells and palm fibers was highly effective in adsorbing cadmium (Cd) and zinc (Zn) from contaminated water. Gopalakrishnan et al. (2012) also confirmed that activated carbon derived from wood and coconut shells was able to remove significant amounts of lead and chromium from water, with adsorption efficiencies reaching up to 85% for certain metals. Additionally, Behera et al. (2014) found that biochar, a form of activated carbon, could be prepared from agricultural waste such as rice husks, which provided a low-cost alternative for water purification. Studies by Apambire et al. (2015) further support these findings, showing that activated carbon made from local biomass is a viable option for reducing fluoride contamination in groundwater. Sharma et al. (2021) concluded that the use of biochar and activated carbon derived from locally available materials not only provides an affordable means of water purification but also promotes sustainability by utilizing agricultural and industrial waste products. These findings suggest that the adoption of activated carbon adsorption technologies can help mitigate the risks associated with heavy metal and fluoride contamination in water sources.

3. Research Methodology

Sample Collection:

Water samples were collected from five villages in Mahendragarh: Atali, Bachhod, Bajar, Chandpura, and Gokalpur.

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These locations were selected based on their proximity to industrial areas and agricultural zones.

Analysis Techniques:

- Inductively Coupled Plasma Mass Spectrometry (ICP-MS) and Atomic Absorption Spectroscopy (AAS) were used to measure the concentration of heavy metals in water samples.
- Activated Carbon Preparation: Activated carbon was prepared from leaves of Brassica Juncea and Helianthus Annus, treated with sulfuric acid. The surface area and adsorption capacity of the carbon were analyzed using FTIR and SEM.
- Health Risk Assessment: The hazard quotient (HQ) for each heavy metal was calculated based on concentration levels and exposure duration.

Preservation of Samples:

Water samples were preserved in clean polythene bottles, and various parameters such as pH, electrical conductivity, total dissolved solids (TDS), and dissolved oxygen (DO) were analyzed immediately or within 24-48 hours of collection.

4. Results and Discussion

4.1 Heavy Metal Contamination Levels in Groundwater Samples

The analysis of water samples collected from five villages in Mahendragarh district revealed concerning levels of heavy metal contamination. Using Inductively Coupled Plasma Mass Spectrometry (ICP-MS) and Atomic Absorption Spectroscopy (AAS), concentrations of lead (Pb), cadmium (Cd), chromium (Cr), and copper (Cu) were measured, with results exceeding the WHO permissible limits for several of the metals, indicating substantial contamination. The detailed concentrations are presented in Table 1.

Table 1: Heavy Metal Concentration in Groundwater Samples (mg/L)

Location	Lead (Pb)	Cadmium (Cd)	Chromium (Cr)	Copper (Cu)	WHO Limit (mg/L)
Atali	0.1	0.02	0.5	0.3	Pb: 0.01, Cd: 0.003, Cr: 0.05, Cu: 2
Bachhod	1.5	0.05	1.2	0.5	Pb: 0.01, Cd: 0.003, Cr: 0.05, Cu: 2
Bajar	3.2	0.3	1.5	1.1	Pb: 0.01, Cd: 0.003, Cr: 0.05, Cu: 2
Chandpura	0.6	0.1	0.9	0.6	Pb: 0.01, Cd: 0.003, Cr: 0.05, Cu: 2
Gokalpur	2.0	0.2	1.0	0.8	Pb: 0.01, Cd: 0.003, Cr: 0.05, Cu: 2

Observation: The concentration of lead (Pb) in Bajar reached 3.2 mg/L, which is 320 times higher than the recommended limit set by the WHO. Similarly, cadmium (Cd) and chromium (Cr) concentrations exceeded safe levels in several locations, particularly in Bajar and Chandpura, indicating a significant contamination problem.

4.2 Efficiency of Activated Carbon in Heavy Metal Removal

The study also assessed the adsorption efficiency of activated carbon prepared from Brassica Juncea leaves, which were treated with sulfuric acid to enhance their adsorption capacity. The results were highly promising, with activated carbon reducing heavy metal concentrations significantly, particularly for Pb and Cu. The removal efficiencies of each metal are summarized in Table 2.

Table 2: Adsorption Efficiency of Activated Carbon from Brassica Juncea Leaves

Metal Type	Initial Concentration (mg/L)	Final Concentration (mg/L)	Removal Efficiency (%)
Lead (Pb)	3.2	0.48	85%
Cadmium (Cd)	0.3	0.09	70%
Chromium (Cr)	1.5	0.45	70%
Copper (Cu)	1.1	0.16	85%

Observation: The activated carbon prepared from Brassica Juncea leaves exhibited high adsorption capacities, with lead (Pb) and copper (Cu) being removed by 85%. Chromium (Cr) and cadmium (Cd) were removed by 70%, which indicates that this low-cost, sustainable material can effectively treat contaminated groundwater.

4.3 Functional Groups in Activated Carbon - FTIR Analysis

To understand the mechanism behind the heavy metal adsorption, Fourier Transform Infrared Spectroscopy (FTIR) was used to analyze the surface functional groups present in the activated carbon prepared from Brassica Juncea leaves. The FTIR spectra indicated the presence of several functional groups, which are critical for the adsorption process. These functional groups interact with metal ions, promoting their removal from water.

Table 3: FTIR Functional Group Analysis of Activated Carbon

Functional Group	Wavenumber (cm^{-1})	Assignment
Hydroxyl (-OH)	3400	Surface hydroxyl groups
Carboxyl (-COOH)	1700	Carboxyl groups responsible for metal ion binding
Aromatic (C=C)	1600	Aromatic structure contributing to the carbon matrix
Carbonyl (C=O)	1300	Carbonyl groups involved in metal adsorption

Observation: The presence of hydroxyl (-OH) and carboxyl (-COOH) groups confirms the ability of Brassica Juncea-based activated carbon to effectively adsorb heavy metal ions through electrostatic interactions and chelation.

4.4 Health Risk Assessment Based on Contamination Levels

A Health Risk Assessment (HRA) was conducted for the metals found in the water samples, with the Hazard Quotient (HQ) calculated for each metal. The HQ is used to evaluate the potential health risk associated with exposure to specific contaminants. A HQ greater than 1 indicates a potential health risk, especially for sensitive populations such as children.

Table 4: Health Risk Assessment of Heavy Metals in Water Samples

Metal Type	Hazard Quotient (HQ)	Risk Level	Comments
Lead (Pb)	1500	High Risk	Extremely high risk, especially for children

Cadmium (Cd)	50	Moderate Risk	Chronic exposure can cause kidney damage
Chromium (Cr)	30	Moderate Risk	Prolonged exposure leads to cancer risk
Copper (Cu)	5	Low Risk	Generally safe, but prolonged exposure may cause gastrointestinal issues

Observation: The HQ for lead (Pb) in some locations, particularly Bajar, is 1500, indicating an extremely high health risk, particularly for children, who are more susceptible to neurological damage from lead exposure. Cadmium (Cd) and chromium (Cr) present moderate risks, while copper (Cu) posed a low risk in the water samples analyzed.

4.5 Water Quality Parameters Before and After Treatment

In addition to heavy metal removal, water quality parameters such as pH and Electrical Conductivity (EC) were measured before and after treatment with activated carbon. The results indicate that the activated carbon treatment not only reduces metal concentrations but also improves overall water quality by decreasing the ionic load and making the water more suitable for consumption.

Table 5: Water Quality Parameters Before and After Activated Carbon Treatment

Location	pH (Before)	pH (After)	Electrical Conductivity (Before)	Electrical Conductivity (After)
Atali	7.2	7.5	520 µS/cm	490 µS/cm
Bachhod	6.9	7.3	480 µS/cm	470 µS/cm
Bajar	6.5	7.0	600 µS/cm	560 µS/cm
Chandpura	7.1	7.4	510 µS/cm	495 µS/cm
Gokalpur	6.8	7.1	530 µS/cm	500 µS/cm

Observation: The pH of the water increased after treatment, suggesting that the water became closer to neutral. This makes the water more compatible for drinking and agricultural use. The decrease in electrical conductivity reflects a reduction in the concentration of dissolved ions, including harmful metals.

5. Discussion

The contamination of water resources with heavy metals has become a critical environmental and public health issue globally, and the Mahendragarh district in Haryana is no exception. The findings from this study indicate high concentrations of heavy metals such as lead (Pb), cadmium (Cd), chromium (Cr), and copper (Cu) in groundwater samples from several villages in the district. These metals pose significant risks to human health, as their prolonged exposure can lead to serious conditions such as neurological disorders, renal dysfunction, and cancer (Gopalakrishnan et al., 2012). The analysis revealed that Bajar and Gokalpur had lead concentrations as high as 3.2 mg/L and 2.0 mg/L, respectively, which is 320 times above the WHO permissible limit of 0.01 mg/L for lead in drinking water. Additionally, other metals such as cadmium and chromium also exceeded the safe limits in many samples, which raises alarms about the overall water quality and the health risks posed to local populations, especially children who are particularly vulnerable to the neurotoxic effects of lead exposure (Apambire et al., 2015).

Heavy metals enter the water system from various anthropogenic activities, including industrial effluents, agricultural runoff, and mining operations (Gopalakrishnan et al., 2012). In Mahendragarh, heavy metal contamination is exacerbated by industrial activities in nearby areas, such as cement factories, electroplating units, and pharmaceutical plants, which discharge untreated wastewater containing toxic metals into rivers and groundwater sources. These findings are consistent with those of Behera et al. (2014), who also observed significant

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contamination of groundwater near industrial zones in West Bengal, India, with metals like zinc and cadmium exceeding WHO limits. Agricultural runoff further worsens the problem, as fertilizers and pesticides, along with metals like cadmium and zinc, enter water bodies, making the water unsuitable for consumption (Ashley & Burley, 2017).

The findings from Jha (2010) and Kumar & Saxena (2011) in the context of fluoride contamination in Mahendragarh are also noteworthy. Both studies found elevated fluoride levels in the region, often in conjunction with heavy metal contamination. Fluoride concentrations in Mahendragarh groundwater were recorded as high as 3 mg/L, which far exceeds the WHO guideline of 1.5 mg/L for drinking water. This dual contamination of heavy metals and fluoride represents a major public health concern in the district. Fluoride, when present in high concentrations, can lead to dental and skeletal fluorosis, both of which result in the weakening of bones and teeth, often causing physical disabilities (Kumar & Saxena, 2011).

In addressing the problem of heavy metal contamination, one of the most effective and sustainable solutions is activated carbon adsorption. The study explored the use of activated carbon derived from Brassica Juncea and Helianthus Annus, which were treated with sulfuric acid to enhance their adsorption capacities. The results were promising, as the activated carbon effectively removed up to 85% of lead (Pb) and copper (Cu), and 70% of cadmium (Cd) and chromium (Cr), as shown in Table 2. These findings are consistent with previous studies that have demonstrated the efficacy of activated carbon as a low-cost, eco-friendly material for heavy metal removal (Boyle & Chagnon, 2018; Gopalakrishnan et al., 2012).

The FTIR analysis provided further insight into the adsorption mechanism of activated carbon. The spectra revealed key functional groups such as hydroxyl (-OH), carboxyl (-COOH), and aromatic groups that play a significant role in chelation and electrostatic interactions with heavy metal ions (Boyle & Chagnon, 2018). This supports the hypothesis that activated carbon, with its large surface area and high porosity, can efficiently remove toxic metals from contaminated water, making it an ideal candidate for water treatment, particularly in rural areas where conventional water treatment methods may be economically unfeasible.

The Health Risk Assessment (HRA) conducted in this study highlighted the high health risks posed by lead (Pb) contamination. The Hazard Quotient (HQ) for lead in certain areas, such as Bajar, was as high as 1500, indicating an extremely high risk, particularly for children who are more susceptible to lead poisoning. Cadmium (Cd) and chromium (Cr) presented moderate risks, with HQ values of 50 and 30, respectively. These findings align with Apambire et al. (2015), who identified similar health risks in Ghana, where lead and fluoride contamination led to dental fluorosis and neurological disorders among the local population.

Additionally, the water quality parameters such as pH and electrical conductivity (EC), measured before and after treatment with activated carbon, further confirmed the effectiveness of this method. The pH of water samples increased after treatment, indicating a shift toward more neutral water, which is more suitable for drinking and agricultural use. The electrical conductivity (EC), a measure of the ionic load in water, decreased significantly, suggesting a reduction in the concentration of dissolved ions, including the harmful heavy metals. This indicates that the activated carbon treatment not only improves the water's chemical composition but also enhances its suitability for human consumption and agricultural irrigation.

This study contributes to the growing body of literature on heavy metal contamination in groundwater and presents a viable, cost-effective solution for water treatment. The use of locally sourced activated carbon derived from indigenous plants such as Brassica Juncea presents a sustainable approach for addressing the problem of contaminated water, especially in rural areas with limited access to expensive treatment technologies (Sharma et al., 2021). Moreover, the results suggest the need for policy reforms aimed at reducing industrial effluents, enhancing water quality monitoring, and promoting public awareness about the risks of contaminated drinking water.

The contamination of groundwater in Mahendragarh district by heavy metals and fluoride presents a significant challenge to public health. The use of activated carbon, especially derived from local plant materials, offers an effective solution for reducing heavy metal concentrations in groundwater. However, immediate intervention is required to implement more stringent pollution control measures, improve water treatment technologies, and raise awareness about the potential health risks associated with waterborne heavy metals and fluoride. Future research should focus on scalability, long-term efficacy, and cost-effectiveness of activated carbon as a sustainable solution for heavy metal contamination in drinking water.

6. Conclusion

This study confirms that heavy metal contamination in groundwater in Mahendragarh district is a significant concern, with several water sources exceeding safe limits for lead, cadmium, and chromium. The use of activated carbon derived from locally available tree leaves proves to be an effective, sustainable solution for removing heavy metals from water, making it a viable option for water treatment in rural areas. Immediate action is required to reduce heavy metal exposure through defluoridation and pollution control measures. Policy recommendations include the implementation of stricter regulations for industrial effluents, the promotion of green technologies, and awareness programs for the local population regarding the risks of waterborne heavy metals.

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