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Cadmium Toxicity in Drinking Water: A Case Study of Sialkot, Risk Assessment, Cancer Risks, and Public Health Implications

Research Article

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Abstract

Groundwater is the primary source of freshwater, but it is increasingly contaminated due to human activities. In rural areas, fertilizers contribute to water impurities, while in commercial areas, industrial discharge and e-waste dumping cause heavy metal seepage into groundwater. Cadmium and lead, primarily used in battery manufacturing, are significant pollutants. This study analyzed 20 water samples from Sialkot city, collected from wells, filtered water, and public taps in rural and commercial sites. Cadmium concentrations exceeded the WHO permissible limit of 0.003 mg/L, with levels ranging from 0.004 to 0.7 mg/L, particularly higher in commercial areas due to increased waste dumping. Inefficiency of filtered plants was observed, as cadmium requires activated carbon filters for removal. The unique chemical properties of water allow it to absorb pollutants from its surroundings, resulting in contamination from human, animal, and biochemical activities. Heavy metals cause severe health issues, including damage to the cardiovascular system, gastrointestinal tract, CNS, endocrine glands, kidneys, liver, lungs, and bones. The study highlights the urgent need to identify contamination sources, implement control measures, and create public awareness. Comparative analysis revealed higher pollution levels in commercial areas. Questionnaire responses also indicated historical cases of kidney failure and gallbladder stones among the affected population.

Keywords: Chronic Disorder; Hazard Quotient; Lifetime Cancer Risk; Sustainable Developmental Goals

Abbreviations

CNS: Central Nervous System;WHO:World Health Organization; CKD: Chronic kidney disorders;HQ:Hazard quotient;LCR: Lifetime Cancer Risk;SDG:Sustainable Development Goals

Introduction

Water is the most fundamental requirement for human, plant, and animal life and is commonly found from two natural sources: fresh surface water (lakes and rivers) and groundwater. Groundwater is obtained from wells and bore wells. The chemical properties of water, due to its polarization and hydrogen bonds, enable it to suspend, dissolve, and absorb various substances in natural water. However, this ability makes it susceptible to pollution from nearby sources, including human and animal activities, as well as other biochemical processes [1]. Environmental contamination by toxic substances is a growing concern for local users. A wide range of pollutants is constantly introduced into aquatic environments, primarily due to amplified industrial activity, technological development, growing human populations, misuse of natural resources, agricultural practices, and domestic waste runoff. Among these pollutants, heavy metals are the most hazardous because of their persistent nature, toxicity, ability to accumulate in organisms, and tendency to magnify through the food chain. Moreover, they are non-degradable. Heavy metals cause significant toxicity in humans, damaging the cardiovascular and gastrointestinal systems, central nervous system (CNS), endocrine glands, kidneys, liver, lungs, and bones [1].

Heavy metals such as Cd, arsenic, lead, chromium, copper, and mercury in drinking water are most often linked to human poisoning. Some of these metals are essential for life in small amounts, whereas others have no biological function. However, all are highly toxic in large doses and are therefore considered environmentally hazardous substances. Cd is an extremely toxic heavy metal, even in low concentrations. It leaches into the soil through water and further bio-accumulates in organisms and ecosystems. Additionally, Cd has a long biological half-life in the human body, ranging from 10 to 33 years.[2]. Long-term exposure to Cd induces renal damage, disturbs calcium metabolism in the body, and has been linked to cases of prostate cancer and lung cancer. Kidney and gallbladder stones are common results of the long-term intake of contaminated water. Thus, Cd is considered a priority pollutant from a monitoring perspective by most countries and international organizations. The contamination of water is directly related to water pollution; hence, there is a need to continuously monitor the quality of underground and surface water sources.

In the kidneys, Cd in complexes with proteins, including Metallothionein, undergoes glomerular filtration and may be taken up by the same receptors and transporter systems in cortical and distal tubules that are involved in the reabsorption of proteins and nutrients. These may include ZIP8, ZIP10, ZIP14, DMT1, megalin, hNGAL receptor, TRPV5, and cysteine transporter. Previously, megalin and cubilin were suggested to mediate endocytosis of filtered CdMT, but this system exhibits only low affinity for CdMT. Thus, the role of megalin and cubilin in tubular CdMT uptake is questionable. To date, the mechanisms for tubular CdMT internalization remain unresolved [3].

Cadmium is not considered to be redox-sensitive, as it occurs in aqueous solution

Almost exclusively in its Cd^{2+} redox state, although changing redox conditions control Cd release and retention in aquifers. It is highly mobile in oxic and acidic waters. Cadmium can form soluble organic and inorganic complexes, such as $CdCl^{+}$, $CdCl_2^0$, $CdSO_4^0$, $Cd(CO_3)_2^{2-}$, and $CdOH^{+}$, which decrease Cd sorption under anoxic and more alkaline conditions. To evaluate Cd mobility, it is necessary to consider the different redox environments in an aquifer, specifically oxic, suboxic, nitrate-reducing, Mn(IV)reducing, Fe (III)-reducing, sulfate-reducing, and methanogenic conditions, which depend on the chemical composition of groundwater, microbially catalyzed reduction processes, and the behavior of the dominant redox couples. Hence, in addition to the sole use of redox potential and pH, microbially induced redox processes in groundwater can provide indicator parameters for conditions that affect Cd mobility. Iron and manganese, along with their minerals, play an important role in environmental biogeochemistry regarding sorption, co-precipitation, and electron exchange, making them ideal proxies to monitor redox processes and the mobility of trace metals such as Cd. [4].

Rationale of the Study

- Development of an understanding of the specific system and its capability to supply water that meets health-based targets.
- Identification of potential sources of contamination and how they can be controlled.
- Validation of control measures employed to manage hazards.
- Implementation of a system for monitoring the control measures within the water system.
- Timely corrective actions to ensure that safe water is consistently supplied.
- Undertaking verification of drinking water quality to ensure that the water safety program is being implemented correctly and is achieving the performance required to meet relevant national, regional, and local water quality standards or objectives.

Aims and Objectives

- To confirm the presence of a particular disease (gallbladder and kidney stones) due to the specific heavy metal (Cd).
- To ensure the contamination of drinking water through complete sample collection and analysis.
- To conduct training sessions and awareness campaigns for public health protection, as the suggestions and recommendations will be meaningful after analysis and results compilation.
- To compare the groundwater contamination levels by heavy metals in rural and urban areas.

Problem Statement

Drinking water contamination increases day by day due to development (pesticides, fertilizers, and solid waste) and the industrial revolution. In ancient times, water pollution levels were lower in remote and rural areas, but now they have increased, leading to chronic diseases (renal failure, gallbladder stones, stomach issues) in communities. Therefore, the identification of disease levels and root causes is necessary for proper recommendations and awareness. After the analysis, the results will be accurate, and problem characterization and solutions will be easier.

Literature Review

According to a study conducted by Mohammad Raza Jamali et al., (2014),[5] aluminum (Al) and cadmium (Cd) were determined in groundwater samples and human health risks associated with elevated concentrations of toxic metals in dissolved form were assessed using a novel solid-phase microextraction (SPμE). Groundwater samples ($n = 200$) and biological samples (blood) from patients with chronic kidney disorders (CKD), along with healthy control subjects from the same area (southern part of Pakistan), were collected. The concentration of extracted analytes was determined by an electrothermal atomic absorption spectrometer. The influence of different variables on the extraction efficiency of Cd and Al was optimized. The Al and Cd concentrations in groundwater were found to be elevated above the recommended limits by the World Health Organization. A significant variation in levels of Cd and Al was observed in blood samples of CKD patients compared to referent subjects ($p < 0.01$). A strong positive correlation between Al and Cd levels in groundwater versus

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blood samples of CKD patients ($r = 0.82–0.85$, $p < 0.01$) was observed, compared to those values calculated for referent subjects ($r = 0.425–0.536$).

According to Claire de Burbure et al., (2016) [6] study, lead, cadmium, mercury, and arsenic are common environmental pollutants in industrialized countries, but their combined impact on children's health is little known. The study examined their effects on two main targets: the renal and dopaminergic systems, in over 800 children during a cross-sectional European survey. Control and exposed children were recruited from those living around historical nonferrous smelters in France, the Czech Republic, and Poland. Children provided blood and urine samples for the determination of the metals and sensitive renal or neurologic biomarkers. Serum concentrations of creatinine, cystatin C, and β2-microglobulin were negatively correlated with blood lead levels (PbB), suggesting early renal hyperfiltration, which averaged 7% in the upper quartile of PbB levels (> 55 μg/L; mean, 78.4 μg/L). The urinary excretion of retinol-binding protein, Clara cell protein, and N-acetyl-β-d-glucosaminidase was associated mainly with cadmium levels in blood or urine and with urinary mercury. All four metals influenced the dopaminergic markers serum prolactin and urinary homovanillic acid, with complex interactions brought to light. Heavy metals polluting the environment can cause subtle effects on children's renal and dopaminergic systems without clear evidence of a threshold, which reinforces the need to control and regulate potential sources of contamination by heavy metals.

According to Gunnar F (2017) [7] a study conducted a few years ago suggested that cadmium was thought by most researchers to be of toxicological importance only in industry. In the late 1960s, it was established as the cause of an epidemic of osteomalacia in Japan (Itai-Itai disease), and recent investigations indicate that it may be causally associated with an increase in the prevalence of proteinuria in several areas in Japan where the general environment has been contaminated by cadmium. The high chronic toxicity of cadmium is explainable on the basis of its long retention time (biological half-life in the order of decades) in the human kidney, leading to an accumulation of cadmium, especially in the renal tubules. This accumulation, when reaching a level of about 200 μg Cd/g, may cause renal dysfunction. Based on the experience of the toxicity of cadmium for animals and humans, a metabolic model has been established describing the accumulation of cadmium in the kidney, and from this model, calculations of critical daily intakes through food and inhaled air have been made. A comparison of these calculated effect values with existing safety values for industry shows that the latter are far too high.

Magdalena Mezynska et al., (2018) [8] conducted a study on the health hazards of cadmium. Cadmium (Cd) is a heavy metal belonging to the group of the main chemical pollutants of the natural and occupational environment in economically developed countries. The forecasts indicate that contamination of the environment with this toxic metal, and thus the exposure of the general population, will increase. Food (particularly plant products) is the main source of t he general population's exposure to this element. Recent epidemiological studies have provided numerous evidences that even low-level environmental exposure to this toxic metal, nowadays occurring in numerous economically developed countries, creates a risk for the health of the general population. Low-level lifetime exposure to this metal may lead to damage to the kidneys, liver, skeletal system, and cardiovascular system, as well as deterioration of sight and hearing. Moreover, it has been suggested that environmental exposure to this xenobiotic may contribute to the development of cancer of the lung, breast, prostate, pancreas, urinary bladder, and nasopharynx. Taking the above into account, the aim of this review article is to draw more attention to Cd as an environmental risk factor for the health of the general population and the need to undertake preventive actions to reduce the risk of health damage due to lifetime exposure to this toxic metal.

The study was performed by Mehdi Qasemi et al., (2019) [9] to estimate the concentration of cadmium and the health risk to humans from cadmium through the ingestion of groundwater in 39 rural areas of Gonabad and Bajestan, eastern Iran. The mean cadmium concentrations in groundwater in the studied rural areas of Gonabad and Bajestan ranged from 0.087 to 14.32 μg/L and from 0.417 to 18.36 μg/L, respectively. The health risk quotient for cadmium contamination for 16% and 38% of children and infants in rural areas of Gonabad and Bajestan, respectively, was more than 1, which causes non-carcinogenic risk to the local population. The carcinogenic risk of cadmium in drinking water for adults, children, and infants in 16%, 33%, and 33% of studied rural areas of Gonabad and Bajestan, respectively, was higher than the safe limit of 1.0×10^{-4}. For rural areas of Bajestan, the cancer risk in 42%, 52%, and 52% of adults, children, and infants was above the safe limit. It was strongly suggested that accessible treatment procedures should be taken for a portion of contaminated rural areas before the distribution of the groundwater to the local population.

Minhaz Farid Ahmed et al., (2020) [10] reported that toxic Cd (cadmium) and Cr (chromium) in the aquatic environment mainly originate from natural sources; however, human activities have increased their concentrations. Several studies have reported higher concentrations of Cd and Cr in the aquatic environment of Malaysia; however, the association between metal ingestion via drinking water and human health risk has not been established. This study collected water samples from four stages of the drinking water supply chain at the Langat River Basin, Malaysia, in 2015 to analyze the samples by inductively coupled plasma mass spectrometry. The mean concentrations of Cd and Cr, along with the time-series river data (2004–2014) of these metals, were significantly within the safe limit of drinking water quality standards proposed by the Ministry of Health Malaysia and the World Health Organization. Hazard quotient (HQ) and lifetime cancer risk (LCR) values of Cd and Cr in 2015 and 2020 also indicate no significant human health risk from their ingestion via drinking water. Additionally, the management of pollution sources in the Langat Basin from 2004 to 2015 decreased Cr concentration in 2020 based on the autoregression moving average. Although Cd and Cr concentrations were found to be within the safe limits at Langat Basin, high concentrations of these metals have been found in household tap water, especially due to contamination in the water distribution pipeline. Therefore, a two-layer water filtration system should be introduced in the basin to achieve the United Nations

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Sustainable Development Goals (SDGs) 2030 agenda of a better and more sustainable future for all, especially via SDG 6 of supplying safe drinking water at the household level.

Methodology

Study Area

The study area is situated in Sialkot, Pakistan. This city is Pakistan's 13th largest city by population. It is located in northeast Punjab. It features a humid subtropical climate with four seasons and an average rainfall of 957.9 mm. The average temperature during the overall region was between 28°C and 50°C. Risk assessment and sample collection will be from selected villages and commercial areas (Kundan Pur and Haripur) in Punjab (Sialkot), Pakistan. The selected areas' population of the village is almost 2 lac and the population of the city and commercial area is a maximum of around 4-5 lakh. Most people are educated and well aware of the contamination, but older people still utilize groundwater directly without treatment, and they suffer from diseases like renal failure and kidney stones. So, the research will focus on evaluating whether heavy metal (cadmium) is the cause of the problem. Cadmium is the metal that gradually forms layers in the renal system, causing kidney stones and gallbladder issues, as well as stomach infections.

Qualitative Survey

A qualitative survey will be conducted for the development of the questionnaire and problem identification. The survey will be done in both urban and rural areas. The questionnaire will be filled out to ensure that personal observations are clear about the diseases caused by heavy metals or if the disease has some other root cause. The questionnaire is comprised of three sections: basic information, occurrence of diseases based on symptoms, and quality of life. The study focuses on the identification of behavior and the impact of selected trace elements on human health. The questions were both open-ended and close-ended and were part of on-the-spot sessions. The analysis has been designed based on age groups. According to personal observations, the community has renal, stomach, and gallbladder problems, but by filling out the questionnaire, a strong reason will be developed for analysis and problem solution.

Material and Methods

Water quality and contamination level will assess by sample collection of ground water and filtered water for the comparison and disease rate evaluation. Samples will be collected from specific study areas (Kundan Pur and Haripur). Total samples are 20 in number, Composite samples be analyzed for the results.

Results and Discussions

Basic Parameter Measurements

Basic parameters should meet the WHO organization limits for proper healthy drinking water uptake. This study revealed that the drinking water quality at commercial sites is more degraded due to industrial discharge and subsequent seepage into the groundwater. The pH of samples is acidic in industrial areas, and the decrease in pH and TDS are the main mechanisms causing Cd in the ground and surface water. On the other hand, the use of fertilizers decreases acidity, increases alkalinity, and slows down the Cd mechanism process in the water, reducing further complications and disease prevalence.

Table 1.1: Sources of sample collection

Sr.No	Sources of Sample Collection	NO. Of Samples
1	Bore well/Hand pumps	4(2 samples from both selected locations)
2	House hold tap water	6 (3 samples from both sites)
3	Filtered water	9(3 samples collected from village and 6 samples collect from the commercial site)
4	Public tap	2(1 sample collect from each site)

Samples will be collected in poly ethylene bottles and the labeling of sites is necessary for the later on analysis. Heavy metals detection will be done by titration and atomic absorption spectroscopy.

Table 1.2: Basic Parameters measurement in rural area

Sr.No	Basic Parameters Of Drinking Water	WHO Limits	Bore well/Hand pump	Filtered Water	Household Water system	Public tap
1	PH	6.5-8.5	9.5	8.5	9.5	9.0
2	Conductivity	1000	1300	800	1200	1250
3	TDS	1000	1500	900	1100	950
4	Turbidity	5	6.5	4.5	6.3	4.5

Table 1.3: Basic Parameters measurement in commercial areas

Sr.No	Basic Parameters of Drinking Water	WHO Limits	Bore well/Hand pump	Filtered Water	Household Water system	Public tap
1	PH	6.5-8.5	10	7.0	9.75	8
2	Conductivity	1000	1500	850	900	800
3	TDS	1000	1700	950	1200	1100
4	Turbidity	5	7.0	4.75	6.0	8.0

• Cadmium Concentration Measurement:

Table 1.4: Cadmium Concentration in collected samples

Sr.No	Sources of Sample Collection	WHO Guidelines	Samples. NO	Commercial Site	Sample. NO	Rural site
1	Bore well, /Hand pump	0.003	S-1	0.07	S-5	0.04
2	Filtered Water	0.003	S-2	0.005	S-6	0.004
3	Household Water System	0.003	S-3	0.04	S-7	0.02
4	Public Tape	0.003	S-4	0.006	S-8	0.004

Cadmium presence in the drinking water is more in the city area se compared to the rural site due to industrialization and the disease prevalence and death rate is also much more due to Cd deposition in the body.

Questionnaire Based Results

- 45% of people have a historical background of family members who had kidney-related diseases.

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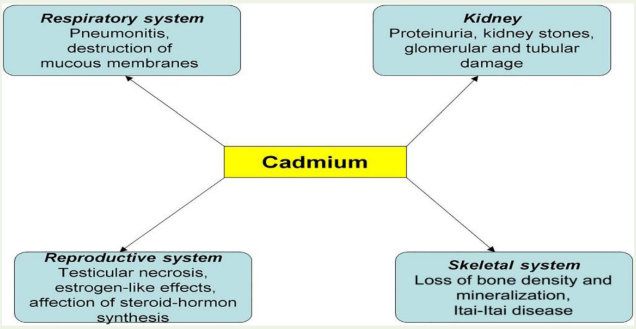

Figure 1.1: Multiple Health Hazards by Cadmium.

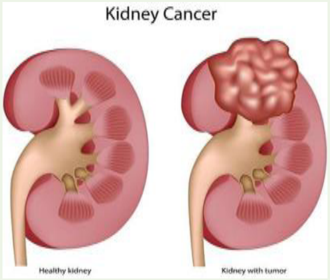

Figure 1.2: Healthy Kidney converts into Unhealthy organ by Cadmium exposure.

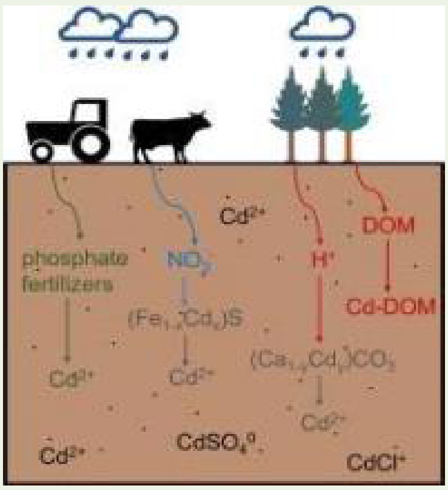

Figure 1.3: Showing workers were not using gloves

- 30% of people have information that their family members had gallbladder stones.
- 50% of people who have diseases are between the ages of 40-60 because their body organs have specific defense problems due to age.
- 90% of people use filtered water, but the concern is that the filters are not activated carbon-based.
- 60% are aware that once a filter plant is installed, it is not cleaned for several years.

Figure 1.4: Rural site for sample collection.

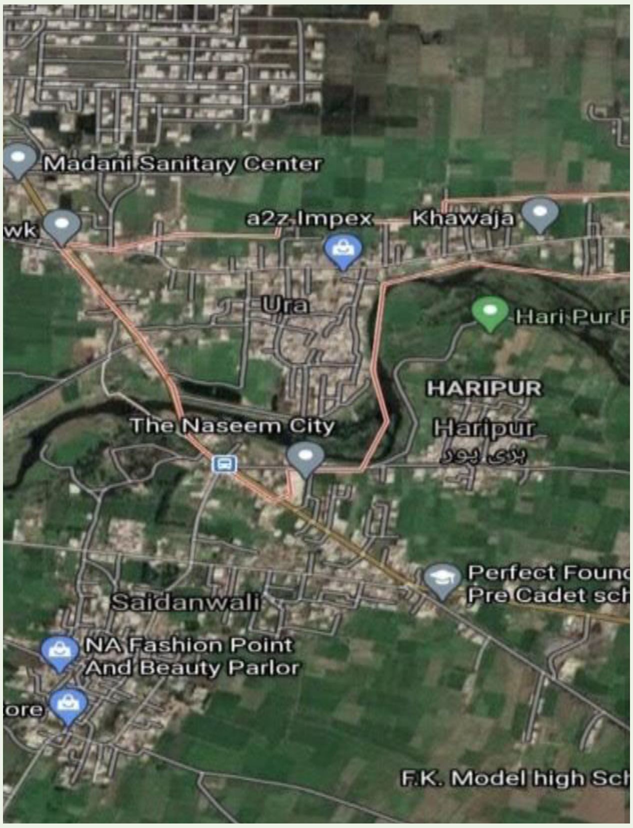

Figure 1.5: Commercial site for sample collection.

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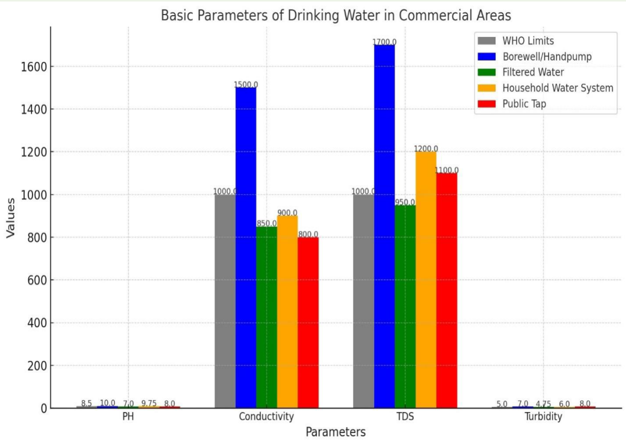

Figure 1.6: Basic parameters measured values in rural areas.

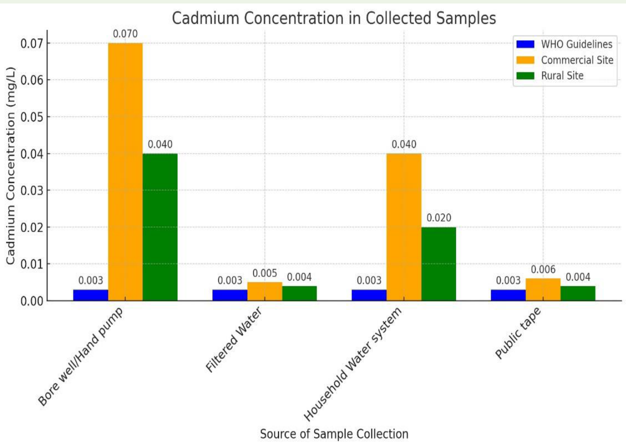

Figure 1.7: Comparison between the rural and commercial sites for the Cd concentration.

Discussion

The findings suggest a worrisome connection between heightened levels of cadmium in the drinking water and the symptoms reported by the surveyed individuals. In areas designated for commerce, where cadmium levels surpassed the permissible limits set by the WHO, a notable percentage of participants disclosed a history of kidney ailments (45%) and gallbladder stone occurrences (30%) within their families. These results are consistent with existing research emphasizing cadmium's tendency to amass in the kidney and gallbladder tissues, potentially causing long-term health issues with prolonged exposure. Moreover, insights from the demographic study indicate that half of the individuals facing these health concerns belong to the 40–60 age bracket, indicating a progressive effect of cadmium toxicity as people age. Additionally, the ineffectiveness of non-activated carbon filtration systems, employed by 90% of participants, worsens the issue by failing to adequately eliminate cadmium. The study also emphasizes how industrialization affects urban regions, leading to increased cadmium levels from improper waste disposal. Conversely, rural areas showed marginally lower cadmium concentrations, yet the application of fertilizers might pose a risk of gradual groundwater pollution. The necessity for public awareness initiatives and efficient water purification technologies is underscored by the prevalence of these health concerns and the elevated levels of cadmium identified. It is imperative to implement routine filtration plant upkeep and integrate activated carbon systems to reduce cadmium exposure and associated health hazards.

Conclusion

In conclusion, the present research revealed that the drinking water samples contain Cd concentrations higher than the permissible limit set by the World Health Organization (2011). Most of the underground water samples were at the populace level and were not recommended for drinking purposes. The contamination results indicate that a major proportion of the populace is at significant risk of Cd toxicity, as the water samples from the commercial and rural sites were highly polluted by the metal. The overall heavy metal pollution situation is at an alarming stage. People may suffer serious health risks due to drinking water with high concentrations of heavy metals. These metals may have physiological effects on the kidney, digestive system, circulatory system, nervous system, and various other organs and systems in the body. Therefore, it is necessary to regularly monitor the toxicity and quality of the water system. Wastewater should be treated before being discharged into water sources.

Recommendations

- To conduct targeted awareness campaigns for communities, especially focusing on middle-class families with limited access to education, and emphasize the dangers of small contaminants that may not be visible to the naked eye, particularly heavy metals like cadmium.
- To organize special sessions for vulnerable groups, such as the elderly and low-income families, to raise awareness about water contamination risks and the importance of regular maintenance of water filtration systems.
- To educate the community about the potential dangers of expired or poorly maintained water filters and highlight that filters can become ineffective if not replaced or cleaned regularly, as their membranes may get clogged with contaminants over time.
- To encourage the installation of activated carbon and reverse osmosis filters, which have proven effectiveness in removing heavy metals from drinking water. These systems should be regularly maintained for optimal performance.
- To prioritize solid waste management strategies to prevent the seepage of cadmium and other heavy metals into groundwater, particularly through the improper disposal of e-waste. Proper recycling and disposal systems for electronic waste (e-waste) should be implemented in communities to minimize environmental contamination.
- To promote the reuse and recycling of e-waste to reduce cadmium deposition in the environment and the human body, encouraging both manufacturers and consumers to participate in sustainable waste management practices.

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- To engage local community leaders to lead the efforts in educating and motivating others to actively participate in proper waste disposal, water purification, and regular testing of water quality.
- To use data from the study to reinforce the importance of implementing these measures to reduce the health risks associated with heavy metal exposure.

Questionnaire

Demographic Questions

1. What is your name? ....
2. Gender of respondent?.......................................

Male Female

3. What is your age? ....
4. Location/ Address ....
5. What is your education ....

Sources of Drinking Water

Which of the following sources of drinking water are available in your neighborhood?(Multiple responses are possible)

- Bore well/ hand pump
- Public tap
- Community well
- Household water supply (piped)
- Other

Which of the following sources of drinking water does your household use? (Multipleresponses are possible)

- Bore well/ hand pump
- Public tap
- Community well
- Household water supply (piped)
- Other

What you noticed about the physical parameters of drinking water?

- Acceptable
- Rejection able

How many times filtration plant clean up in the year

- Once
- More time
- Measuring values meet up with the WHO
- Yes
- No

Disease prevalence

Do you have any patient in the family history about these certain diseases?

- Kidney stone/Kidney failure
- Gallbladder stone
- Liver and lungs related diseases

Do your society have any dead patient of certain disease in social circuit?

- Yes
- No

What was the age of patients

- 10-30
- 30-40
- 40-60

E-Waste dump in the sites

- Yes
- NO

Fertilizer used in the field

- Maximum
- Minimum

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