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RESEARCH ARTICLE

A COMPREHENSIVE ANALYSIS USING THE HEAVY METAL POLLUTION INDEX (HPI) FOR ASSESSING DRINKING WATER QUALITY IN ISLAMABAD

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ABSTRACT

This study aimed to assess the pollution of heavy metals, specifically Cd, Fe, Pb, Ni, Cr, Mn, and Zn, in the water filtration plants of DHA phase II Islamabad, Pakistan. As the zone relies heavily on these sources for in house and drinking purposes, eleven samples were collected and preserved for analysis. Laboratory testing, conducted for all samples using Flame Atomic Absorption Spectroscopy instrument, revealed that levels of Iron, Manganese, and Zinc were within accepted limits in nearly every sample. However, concentrations of Cd, Pb, Ni, and Cr exceeded PAK-EPA standards, suggesting potential health risks. The calculation of the Heavy Metal Pollution Index indicated that most samples were unsuitable for direct consumption, emphasizing the hazardous nature of the water for drinking purposes.

KEYWORDS

Heavy Metal Pollution, Flame Atomic Absorption, Heavy Metal Pollution Index, Pakistan Environmental Protection Agency.

1. INTRODUCTION

Water as an essential component for survival and overall health unfortunately, is often unfit for immediate consumption due to its interaction with soil and rocks. Despite being a primary source for 89% of the global population, pollution and the presence of heavy metals in water persist, as highlighted by the World Health Organization (WHO) (Alam et al., 2017). In recent times, progress in research facilities has enabled scientists to distinctly emphasize the impact of human activities on nature. These metals, recognized as pollutants for the environment because of their toxic levels, long-lasting presence, and tendency to accumulate in living organisms, have both natural origins, such as the disintegration of metal-containing debris rock and eruptions from volcanic activity, and human-induced activities, including mining, as well as diverse industrial and agricultural practices (Ali et al., 2019). Numerous studies from various regions across the country have consistently highlighted issues of inadequate water management and deterioration in water quality, particularly concerning heavy metals. In a recent investigation conducted in the Punjab region, findings revealed that the assessment of geological and chemical parameters indicates elevated toxic levels of the mentioned contaminants, significantly impacting a considerable segments of the people (Iram et al., 2019). Also Hashmi et al., (2009), stated that merely a quarter of Pakistan's population enjoys dependable access to safe drinking water. This study specifically focuses on evaluating the quality of drinking water in terms of heavy metal pollution, the mathematical model, employed to illustrate different contaminated zones concerning particular metal contaminants. Additionally, a comprehensive examination was conducted to assess the overall impacts of the scrutinized pollutants.

1.1 Study Area

The area is located in DHA Phase II, and regionally marks the south eastern boundary of Islamabad. The prevailing geological characteristics here include prominent exposures of the Lesser Himalayas. Collection of water samples, accompanied by the respective coordinates for every collection point, was conducted from various wells and drinking water plants. The figure 1 below illustrates the distribution of sampling sites within the designated study area.

2. METHODOLOGY

2.1 Sampling Preservation and Material

The light weight thermoplastic bottles were selected for sample collection. Initially, the bottles were cleaned with pure water and then soaked necessary for the preservation of sample. The sampling took place mid of August, with each location being recorded using GPS. The sources of water sample were 100 ft deep, and efforts were made to ensure uniform depth across water sample sources for a more accurate comparison.

For preservation, the samples were kept in a refrigerator at 4°C. The specimen was purified then acidulated using 3 ml of solution (HNO_3) in order for maintaining potential hydrogen for all specimens under two, in order to identify heavy metals. following the standard procedure for metal analysis (Chakrabarty & Sarma, 2011). Observations for cadmium, lead, iron, manganese, nickel, chromium, and zinc were conducted utilizing an Atomic Absorption Spectroscopy (AAS) instrument equipped with flame detection. This sophisticated instrumentation proved adept at discerning the presence of heavy metals in water, demonstrating its proficiency in analytical applications.

2.2 HPI Evaluation

Various mathematical models are employed to present the findings for enhanced comprehension. The Heavy Metal Pollution Index (HPI) is a rating method that illustrates the collective impact of individual heavy metals on the overall water quality. This technique was utilized to measure the sources in the samples (Sheykhi & Moore, 2012). The calculation of HPI follows through the given equation (1) below:

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$$HPI = \frac{\sum_{i=1}^{i=n}(Qi \times Wi)}{\sum_{i=1}^{i=n} Wi} \quad (1)$$

The formula for calculating *Wi*, the unit weight of the *ith* parameter, is expressed as follow in equation (2), where *Qi* represents the *ith* parameter sub index, and n marks the total number of variables involved (Abou et al., 2015).

$$Wi = \frac{K}{Si} \quad (2)$$

The following formula yields the value of *Qi*, where *K* is the proportionality constant, usually taken to be 1, and *Si* is the standard value that is allowed for the *ith* parameter:

$$Qi = \sum_{i=1}^{i=n} \frac{|Mi - Ii|}{Si - Ii} \quad (3)$$

The HPI calculation involves the use of monitored values (Mi) for heavy metals of the *ith* parameter, where *Ii* is the optimal value and *Si* is the standard value for the *ith* parameter in ppb (μg/L).The values for Si and Ii were obtained from the source. It is important to note that all obtained results are used in parts per billion format for the HPI calculation (Nazari & Razmara 2014).

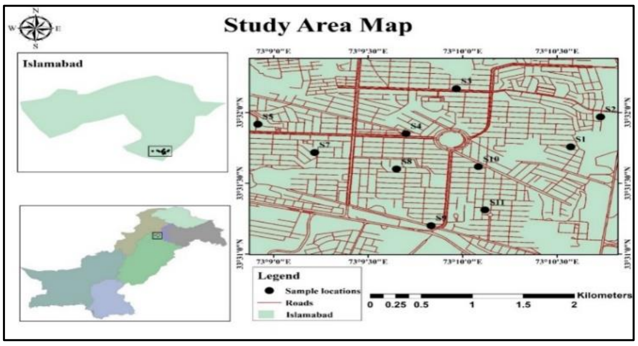

Figure 1: Map representing the sampling sites for the study area.

3. Findings and Interpretation

Specimens obtained from the sampling site in different areas of research, were subjected to heavy metal analysis. The metal concentrations were assessed against both Pakistan environmental protection agency and world health organization standards for drinking water.

The outcomes indicated that Cadmium concentration in water specimens varies off 0 to 0.100 mg/L, reaching a highest range which is 0.100 mg/L in first specimen. All specimens surpassed the desired range for cadmium (0.003 mg/L) (Fig 2, table 1). According to Friberg & Elinder (1993) high acidity levels can facilitate the dissolution of Cd, as commonly present in deep zones around bedrocks (Friberg and Elinder, 1993). Inherently, cadmium is associated with Zn and Pb, existing in the form of FeS_2 (Iram et al., 2019). Elevated Cd levels in filtration supplies can have severe implications for kidney function persistent exposure to high cadmium levels may lead to various health issues, including nausea, vomiting, diarrhea, muscle cramps, excessive salivation, sensory disturbances, liver injury, convulsions, shock, and renal failure (WHO 2011; Iram et al., 2019). Additionally, long-term exposure may result in damage to the kidneys, liver, bones, and blood (Chakrabarty & Sarma, 2011). The PAK-EPA standard for Iron is set at 0.3 mg/L. The concentrations of Fe in the water samples ranged from 0.005 to 0.100 mg/L, with a maximum value of 0.093 mg/L in sample S6. All the samples complied with the standard range as shown in table 1 and Fig 3. Iron is commonly present in drinking water, usually at concentrations below 10 mg/L. Even at 0.3 mg/L, water may exhibit a reddish-brown tint. There are two main forms of Fe in filtration sources: soluble Fe^{2+} and insoluble Fe^{3+}. Fe^{2+} is completely mixed, results the formation of pure water. While Fe is considered a minor pollutant with no significant health risks, it is essential for overall health and plays a role in transporting oxygen in the blood. In South Asia, the majority of tap water supplies approximately 5% of the daily iron requirement (Mock et al., 2018). Lead, as an environmental contaminant, acts as a neurotoxin agent, causing many serious health problems particularly in adults (Lu et al., 2022). Fe contaminates drinking water in various forms, including industrial waste, vehicle emissions, and household paint. The presence of lead poses severe risks to human health according to (Ali et al., 2019). There is no identified safe threshold for blood lead levels, and even low-level lead exposure can be harmful to health (Fawkes & Sansom, 2021). The observed lead concentration in specimens obtained from filtration plants ranges from 0.001-0.034 mg/L, with the maximum range of 0.012 mg/L in one specimen at H zone. Maximum specimens were within the prescribed range set as (0.010 mg/L) as shown in Fig. 4. Regarding Nickel, one specimen exhibited the maximum peak value at 0.012 mg/L. Nickel concentrations exceeded the standard range (0.020 mg/L) in different specimens. Nickel results were matched with the range limit of 0.020 mg/L as shown in Fig. 5. High nickel levels in drinking water can result from nickel-plated plumbing, faucets, kettles, or well components, along with contributions from industrial activities and effluent discharge. Hypersensitivities and eczema are commonly occurring with this metal exposure. Long-term exposure may increase the risk of renal problems. While Ni concentrations results to cancer upon inhaling, it remains uncertain whether ingested nickel itself poses a cancer risk (Brouwere et al., 2012). Upon comparing Chromium concentrations with the standard PAK-EPA value of 0.050 mg/L, the study revealed a concentration range of 0 - 0.1043 mg/L, with the highest value being 0.030 mg/L as shown in Fig. 6. Chromium levels in different specimens met the permissible range value. Approximately 73% of the samples were deemed suitable for drinking (Table 1). It is thought that dyestuffs and leather tanning are the main causes of chromium pollution, especially when waste is dumped into streams of water. (Waseem et al., 2014). Elevated concentrations of Cr may induce harmful effects, including issues with the kidneys and liver, as well as an increased risk of cancer (Khan et al., 2015). The study assessed the concentrations of Manganese (Mn) and Zinc in water supplies across different sectors, comparing the results with PAK-EPA standard limits. For Manganese, levels ranged from 0.001 to 0.105 mg/L, with the highest value at 0.022 mg/L as shown in Fig.7. Geological sources, such as basalt and limestone, contribute trace amounts of manganese, while improper waste disposal exacerbates pollution. Elevated Mn concentrations in drinking water may pose mental health risks. Zinc level in this research ranged from 0.0078 to 0.277 mg/L, with the highest value at 0.039 mg/L, below the PAK-EPA limit of 5 mg/L as shown in Fig. 8. Zinc is generally safe in drinking water, though extremely high doses can cause gastrointestinal issues. The study underscores the importance of monitoring these elements in water sources for public health (Friberg & Elinder 1993)

Table 1: Individual outcomes for each heavy metal investigated in study area.

Sample ID	Heavy Metals (mg/L)						
	Cadmium	**Iron**	**Lead**	**Nickel**	**Chromium**	**Manganese**	**Zinc**
S1	0.099	0.017	0.003	0.003	0.003	0.036	0.012
S2	0.006	0.005	0.001	0.008	0.017	0.002	0.008
S3	0.03	0.082	0.019	0.008	0.104	0.002	0.017
S4	0.027	0.007	0.004	0.033	0.002	0.015	0.018
S5	0	0.089	0.009	0.012	0	0.056	0.277
S6	0.038	0.093	0.012	0.081	0.021	0.105	0.034
S7	0.021	0.009	0.034	0.008	0.003	0.011	0.017
S8	0.03	0.019	0.011	0.004	0.079	0.009	0.008
S9	0	0.012	0.02	0.028	0.064	0.007	0.015
S10	0	0.1	0.013	0.008	0.004	0.003	0.019
S11	0	0.063	0.011	0.004	0.041	0.001	0.012

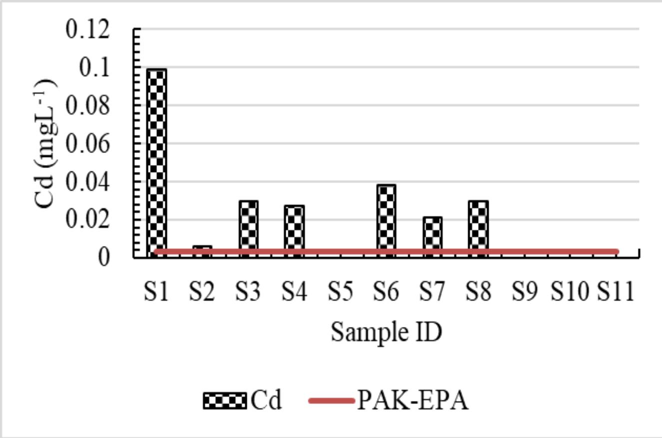

Figure 2: Concentration of Cd in water sample.

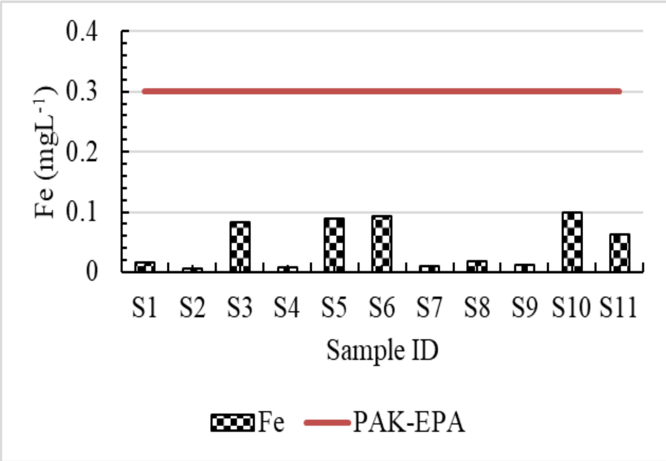

Figure 3: Concentration of Fe in water sample.

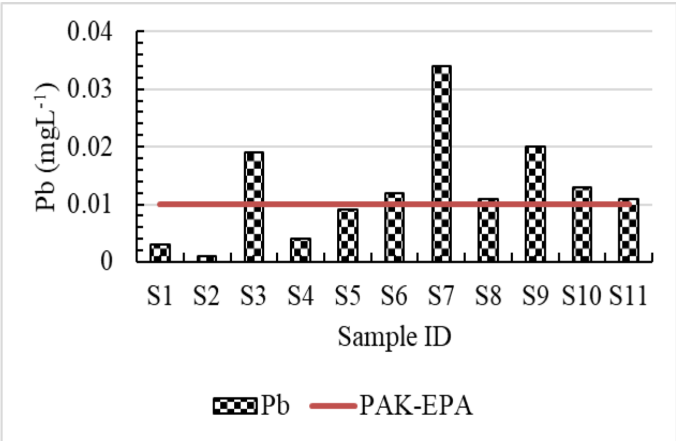

Figure 4: Concentration of Pb in water sample.

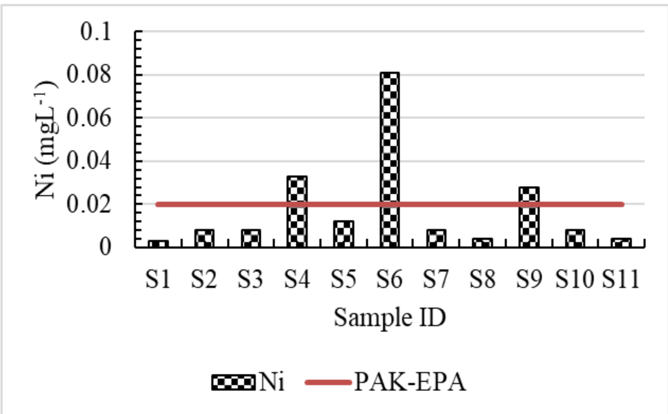

Figure 5: Concentration of Ni in water sample.

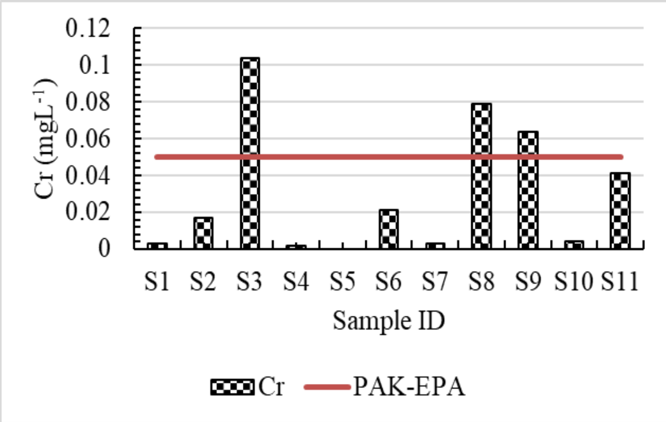

Figure 6: Concentration of Cr in water sample.

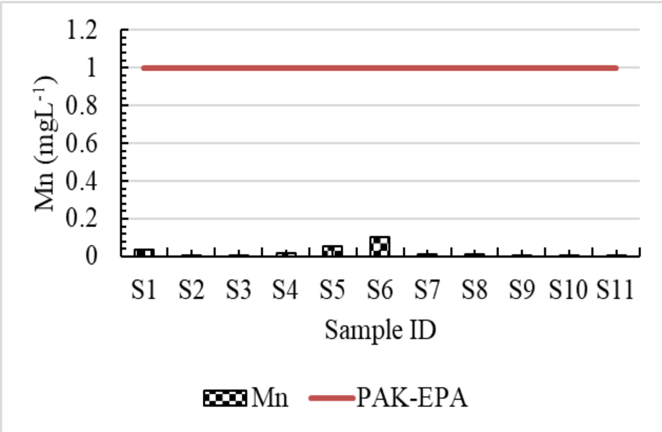

Figure 7: Concentration of Mn in water sample.

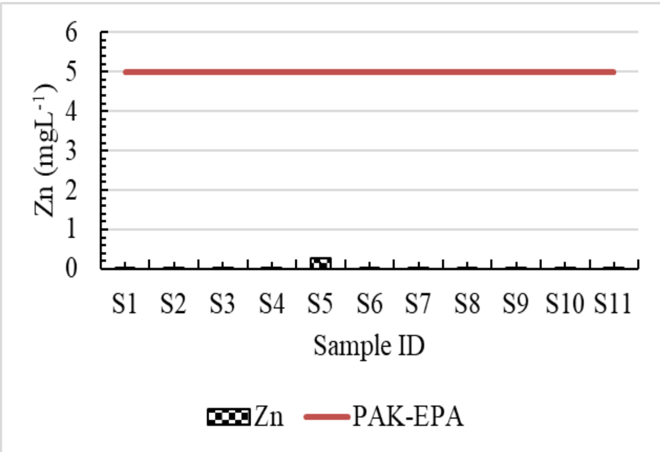

Figure 8: Concentration of Zn in water sample.

Table 2: Findings from the analysis of heavy metal content from each sample.

Metal	No. of samples	Min value (mg/L^{-1})	Max value (mg/L^{-1})	Mean value (mg/L^{-1})	PAK-EPA standard limit (mgL^{-1})	% samples (within limit)
Cadmium	11	0	0.099	0.053	0.01	0%
Iron	11	0.05	0.1	0.04	0.3	100%
Lead	11	0.001	0.034	0.014	0.010	36%
Nickel	11	0.003	0.081	0.018	0.020	73%
Chromium	11	0	0.104	0.030	0.050	73%
Manganese	11	0.001	0.105	0.022	0.500	100%
Zinc	11	0.008	0.277	0.049	5	100%

4. Interpretation

The range obtained after analysis and mathematical derived equations thus computed in every water sample. Typically, a vital HPI value of 100 is considered (Abou et al., 2015). The study assessed water samples using the Health Pollution Index (HPI), with samples under range of hundred is best fit for drinking. The overall HPI values were calculated, and individual HPIs for heavy metals were computed to identify the primary pollutant in each sample. Maps illustrating HPI distribution for each heavy metal were generated. Elevated concentrations for HPI values were attributed for the metals like Cd, Cr, Pb, Zn, Fe, Mn, and Ni. Cadmium showed highest concentration, followed by other metals. Some samples were severely contaminated, also deemed harmful toward utilization, while others fell within safety limits. However, even seemingly safe samples displayed detectable HPI, emphasizing the potential health impact if untreated. The study underscores the importance of assessing individual heavy metals to comprehensively understand water pollution for effective public health management.

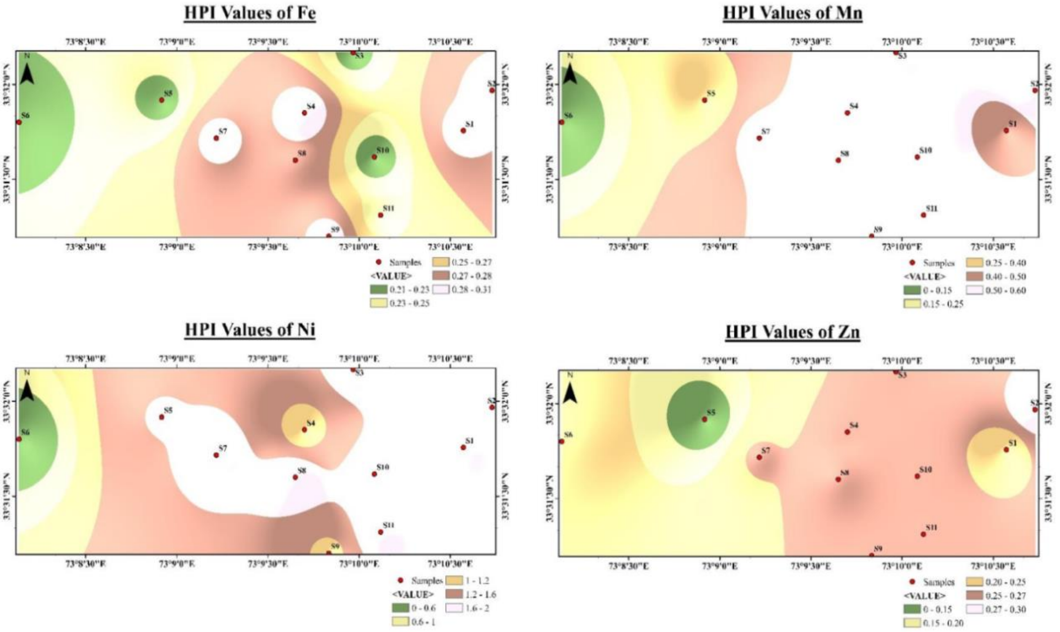

Figure 9: (a) Maps depicting HPI values for various contaminants computed in water samples.

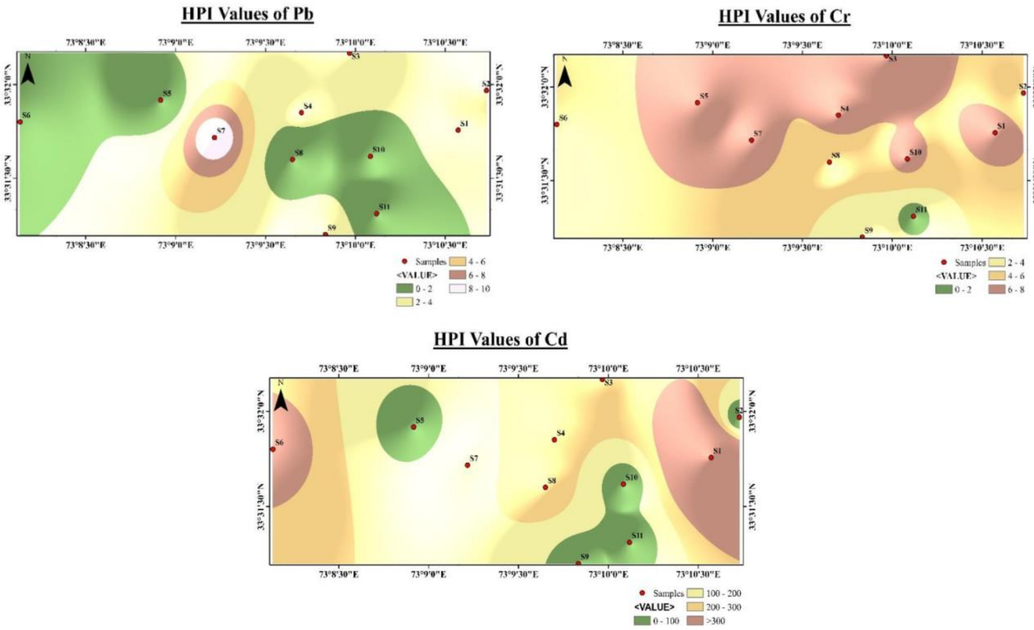

Figure 9: (b) Maps depicting HPI values for various contaminants computed in water samples.

Table 3: Results showing collective values for metals contamination in terms of HPI.

Sample ID	Collective HPI value	Quality for drinking	Remarks
S1	998	Unsuitable	Cd with the 985 HPI is the highest contributor.
S2	42	Suitable	
S3	291	Unsuitable	Cd with the 77 HPI is the highest contributor.
S4	258	Unsuitable	Cd with the 246 HPI is the highest contributor.
S5	41	Suitable	
S6	365	Unsuitable	Cd with the 359 HPI is the highest contributor.
S7	203	Unsuitable	Cd with the 185 HPI is the highest contributor.
S8	285	Unsuitable	Cd with the 277 HPI is the highest contributor.
S9	39	Suitable	
S10	41	Suitable	
S11	35	Suitable	

5. Conclusion

In conclusion, the study on heavy metal pollution in filtration plants revealed alarming concentrations of cadmium, chromium, lead, zinc, iron, manganese, and nickel. These concentrations exceeded PAK-EPA standards, posing a significant risk to human health. Cadmium, in particular, exhibited the highest concentration, raising concerns about its potential adverse effects on the kidneys and other organs. The Heavy Metal Pollution Index (HPI) further emphasized the severity of contaminants, with a notable impact from different metals discussed in this research work. Samples from specific sectors were identified as more toxicants and unsuitable towards utilization, underscoring urgent need for water quality management and treatment measures to safeguard public health.

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