

Human Health Risk Assessment of Selected Heavy Metals Concentration in Drinking Water of Lahore, Pakistan

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ABSTRACT: Developing nations are facing serious problems of heavy metals in their domestic water use, especially in drinking water. The objective of the current study is to analyze heavy metal concentrations such as Arsenic (As), Antimony (Sb), Strontium (Sr), Zinc (Zn), Manganese (Mn) and Barium (Ba) and carrying out health risk assessment in drinking water. A total of 100 drinking water samples were collected from different areas of urban and rural Lahore. Analyses were performed using inductively coupled plasma optical emission spectroscopy (ICP-OES) technique for all selected metal analysis. Associated human health risk assessment was calculated using USEPA mathematical equations. The results revealed that the mean arsenic concentration of well water samples of almost all selected areas ranged 10-30 $\mu\text{g/l}$ exceeding the limits of WHO standard of 10 $\mu\text{g/l}$, while filtered samples were within the range. Other toxic metals concentration of Sb, Sr, Zn, Mn and Ba were mainly within the limits in both well and filtered samples. Hazard quotient (HQ) for arsenic has found between 1-3 (higher than HQ limit of 1) while the other metals HQ were much smaller. HI (hazard index) ranged from 1.01 to 3.93, which was higher than the toxic index value of 1. The ILCR for arsenic was ranged from 4.5E-04 to 1.35E-03 for oral exposure. In conclusion, arsenic concentration in drinking water poses serious threat to public in all selected areas of Lahore.

Keywords: Heavy Metals, Drinking Water, Risk Assessment, Arsenic Exposure, Spectroscopy

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INTRODUCTION

Having access to uncontaminated drinking water is of high importance for human existence and not entail substantial health hazards. Nonetheless, the increasing problem of water scarcity has adverse consequences on global economic progress, human well-being, and environmental conditions (Chowdhury *et al.*, 2016). Heavy metals are prevalent in the environment, including land, water, air, and food sources. They can enter the human body in a number of ways, including through dust inhalation, directly consuming contaminated soil and water, contacting contaminated soil and water through skin, and consuming crops grown in contaminated areas (Anyanwu *et al.*, 2018; Qu *et al.*, 2012).

Water pollution especially in urban areas is caused by diverse hazardous substances, such as heavy metals and various organic and inorganic compounds. Main sources of heavy metals through wastewater discharge are industries (Mohammadi *et al.*, 2019). This wastewater seep into the ground resulting in the heavy metals contamination in groundwater. (Edelstein & Ben-Hur, 2018). Anthropogenic sources, including industrial processes like electroplating, metal smelting, chemical industries, and manufacturing, have a notable impact on water contamination with heavy metals. Insufficient treatment of domestic, industrial, and agricultural wastewater is a prominent contributor in numerous

developing countries, resulting in elevated levels of metals into the environment. Anthropogenic sources, including industrial processes like electroplating, metal smelting, chemical industries, and manufacturing, have a notable impact on water contamination with heavy metals (Siddique *et al.* 2021).

Insufficient treatment of domestic, industrial, and agricultural wastewater is a prominent contributor in numerous developing countries, resulting in the increase of heavy metals concentration into the environment (Zhang *et al.*, 2009). Although groundwater also receives trace elements from a variety of natural sources (Hepburn *et al.*, 2018) The primary cause of heavy metal buildup in the aquatic system is a result of various factors including the presence of different types of bedrock, deposition from the atmosphere, water drainage, runoff from agricultural and urban areas, and the release of industrial waste. Consequently, both surface water and groundwater become polluted with high levels of heavy metals poses serious threat to human health and ecosystem (Ali *et al.*, 2020).

The excessive heavy metal concentration in drinkable water has emerged as a significant public health issue, particularly in developing nations. Exposure to lead and mercury may induce immunological disorders and organ failure (Martin & Griswold, 2009; Fallahzadeh *et al.*, 2017). Other types of metals such as high levels of manganese (Mn) and copper (Cu) in drinking water can

contribute to neurological disorders such as dementia and Alzheimer (Muhammad *et al.*, 2011). Strontium (Sr), an important mineral for bones and teeth, is currently not regulated in drinking water (Al Osman *et al.*, 2019). However, many studies have shown that highly consumption of Sr may have risks to human health by affecting normal bone development (Mahurpawar, 2015; Langley, 2009; Shin, 2017) The imbalance of Sr can inhibit parathyroid gland activity, reduce active vitamin D production in the kidneys, and increase the risk of development of rickets (Peng *et al.*, 2021). Significant diseases are caused by arsenic exposure such as melanosis, high blood pressure, hyperkeratosis, gangrene, skin lesions, peripheral vascular disease, and carcinogenic effects on the lungs and skin (Monteiro De Oliveira *et al.*, 2021). When antimony (Sb) present in elevated concentrations in any ecosystem, it can pose great risks to human health as cancer (Tao *et al.*, 2021; Wu *et al.*, 2011). Toxic exposures to barium (Ba) salts in humans primarily occur through ingestion or inhalation (Peana *et al.*, 2021). The adverse effects commonly associated with toxicity include organ failure, respiratory paralysis, and gastric and intestinal hemorrhages (Kravchenko *et al.*, 2014). These are the most frequently observed health consequences resulting from exposure to toxic barium compounds. Zinc toxicity can have various effects on human health. Ingesting or inhaling zinc through polluted water or inhalation can lead to gastrointestinal issues and tissue modifications (Chiba & Masironi, 1992).

Various literature have shown direct use of drinking water poses health risk to human (Mahmood & Malik, 2014). In Pakistan, only 25.61% of the population, comprising 30% in urban areas and 23.5% in rural areas has access to safe and potable water (Tahir *et al.*, 2010). Various prior investigations have consistently identified elevated levels of heavy metals in groundwater across the regions and districts of Pakistan, exceeding permissible limits.

In 2014 a study has found that the concentrations of heavy metals in groundwater near the industrial area of Kasur, Pakistan, go beyond the quality standards set by the World Health Organization (WHO) (Afzal *et al.*, 2017). A study conducted in 2009 reported that the elevated levels of metals like Manganese (Mn), Zinc (Zn), Lead (Pb), Iron (Fe), Copper (Cu), Nickel (Ni), and Chromium (Cr) are present in the groundwater of Sialkot City, Pakistan (Ullah *et al.*, 2015).

Additionally, a study revealed that the concentration of lead (Pb) in groundwater across Karachi exceeded WHO's permissible limits (Rehman *et al.*, 2018). Moreover, a study in 2019 found high contamination of groundwater with cadmium (Cd), lead (Pb), and zinc (Zn) during the winter season and with Chromium (Cr) and Nickel (Ni) in summer in Rabwah, Pakistan (Iram *et al.*, 2019). Consequently, the

contamination of heavy metals concentration in Pakistan's groundwater poses human health a great risk through several exposure pathways.

The study discovered that while lithium and cadmium had least impacts through dermal and oral routes, chromium (Cr), strontium (Sr), lead (Pb), and cobalt (Co) considerably contributed to chronic exposure among people. While other metals exhibited little to no adverse effects when ingested, Cd, Co, Cr, and Pb presented potential non-carcinogenic health risks (Ali *et al.* 2024). The impact of the heavy metals such as Cd, Cu, As, Pb, Co and toxic trace metals like Ba, Sb, Sr and Mn affect badly on health so there is a special attention to cope with these risks. Further in-depth research is required for better understanding of heavy metals release, impacts and remediation techniques (Sarim *et al.*, 2022). Therefore, the current research focuses to identify and determine potential risks to human health due to heavy metals including Manganese, Antimony, Barium, Strontium, Zinc and Arsenic in drinking water sources.

METHODOLOGY

Study area of the current research: The current study was carried out in four rural areas of Lahore city, Pakistan. The selected areas were Khaliqabad (32° 23' 36" N, 72° 15' 20" E), Hussainabad (31° 31' 16" N and 74° 22' 11" E), Nawazishabad (31° 25' 52" N, 74° 12' 41" E) and EME Housing Society (31° 26' 29" N, 74° 12' 40" E).

Sampling methods: A total of 100 samples were collected as bore water (well water) and drinking water supplies especially filtered water from the selected study areas and assigned the codes such as S1 Khaliqabad Filter, S2 Khaliqabad Bore, S3 Khaliqabad Bore, S4 Khaliqabad Bore, S1 Hussianabad Filter, S2 Hussianabad Bore, S3 Hussianabad Bore, S1 Nawazishabad Filter, S2 Nawazishabad Bore, S3 Nawazishabad Bore, S1 EME Filter, S2 EME Supply, S3 EME Bore. For heavy metals speciation, samples were acidified with concentrated HNO₃. Remaining samples were used to determine pH, EC, TDS, carbonates and bicarbonates.

Before collecting water samples for analysis, water sources such as hand pumps, taps and filters were flushed for 5 minutes to get fresh groundwater (Waqas *et al.*, 2017). Each 125 ml water samples were collected in plastic bottles that were cleaned properly before taking the samples. The bottles were sealed with airtight cap and the samples were preserved at 4°C. After collection, samples were brought to College and Earth and Environmental Sciences, University of the Punjab, Lahore. Water samples were gone through titration to test the presence of carbonates and bicarbonates. Elements were analyzed for each sample through ICP-OES technique. The selected heavy metals were Arsenic,

Barium, Calcium, Potassium, Magnesium, Manganese, Sodium, Antimony, Silicon, Strontium, Zinc, Lead, Cadmium, Copper and Chromium.

Assessment of potential health risk: Potential health risk was calculated by hazard quotient (HQ), chronic

daily intake (CDI), and carcinogenic risk (CR) related to heavy metal exposure. These parameters provide insights into the potential health effects and help guide decision-making processes to safeguard public health (Shakoor *et al.*, 2017).

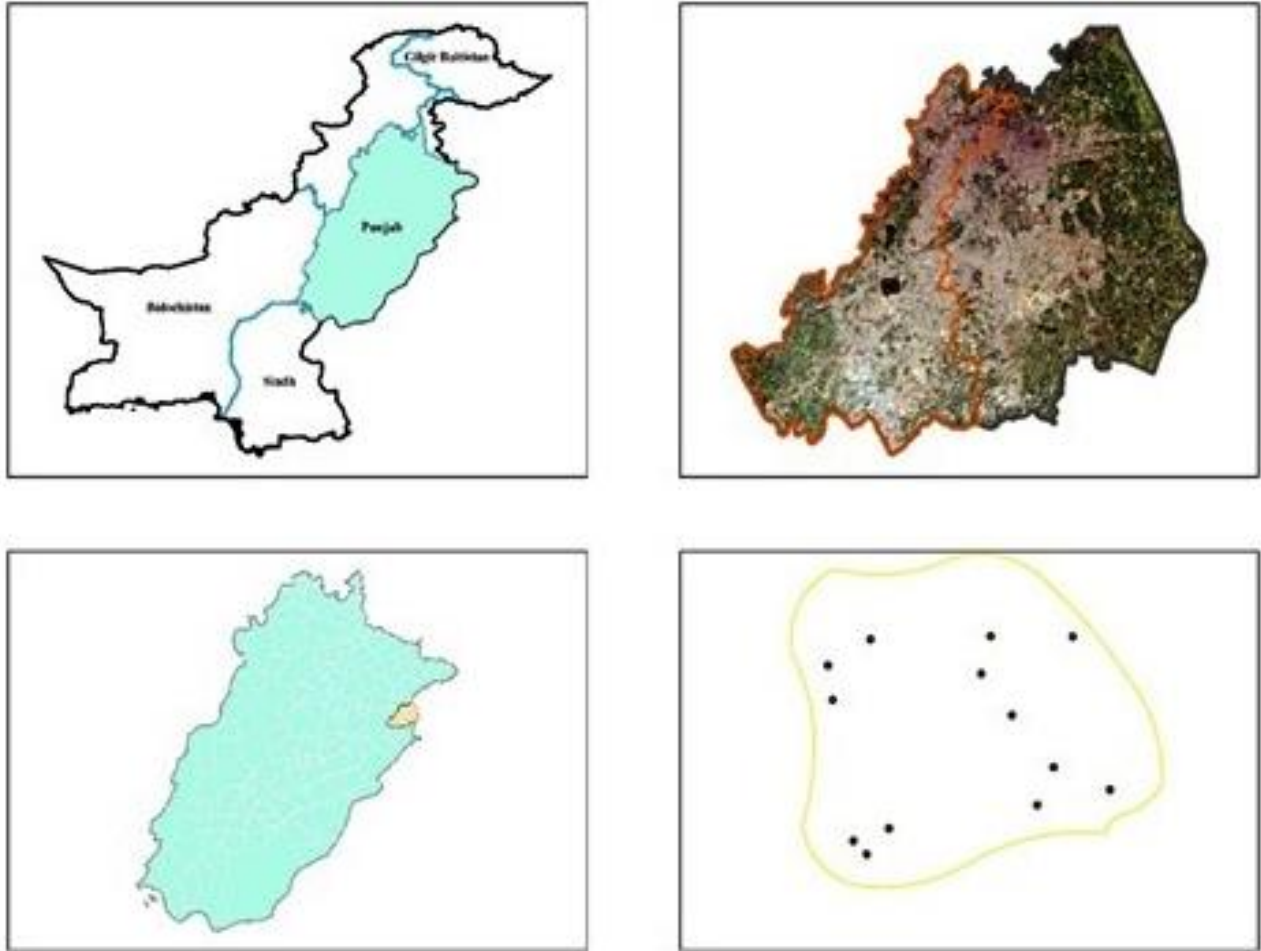


Fig 1. Study area map of groundwater sampling from selected areas of Lahore, Pakistan

Non-carcinogenic analysis: The quantified risk of each toxic metal is expressed in either carcinogenic or non-carcinogenic analysis based on reference-dose (RFD) and slope factor (SF) respectively (Wongsasuluk, 2014). To determine the extent of heavy metal pollution and the potential cancer and non-cancer risk through the route of ingestion of water in selected areas (Khaliqabad, Hussainabad, Nawazishabad and EME), Lahore; Chronic daily intake were calculated using USEPA equation (Means, 1989).

$$CDI = \frac{C \times IR \times ED \times EF}{BW \times AT} \dots\dots\dots(1)$$

Where C represents concentration of a heavy metal (mg/l), IR is Ingestion Rate (in L/day), ED is exposure duration, EF is exposure frequency (days/year), BW is body weight (kg/person) and AT is average life time (years)

The input assumptions used for evaluating CDI are described in Table 1.

Table 1 Parameters and estimated values for ingestion for CDI

Parameters	Unit	Values (for ingestion)
Heavy metal concentration	mg/l	–
Ingestion rate	L/day	2.4
Exposure Duration	Year	70
Exposure Frequency	days/year	365
Body Weight	Kg	80
Average lifetime	Days	25550

Hazard quotient represents the average daily intake ratio of the metal in contaminated water to an RFD that is considered safe for ingestion and dermal exposure (Table 2) (Khan *et al.*, 2009) The calculation for HI is presented as Equation 2. Reference dose for diverse metals is shown in Table 2.

$$HQ = \frac{CDI}{RFD} \dots\dots\dots(2)$$

Where CDI= Chronic daily intake (mg/kg/day) and RFD = Reference dose (mg/kg/day)

Table 2. Values of CSF and References doses (oral) of few heavy metals

Element	RfD (oral)	CSF
Sr	0.6	–
As	0.0003	1.5
Sb	0.0004	–
Ba	0.07	–
Zn	0.3	–
Mn	0.14	–

For the assessment of overall noncarcinogenic health effects resulting from being exposed to heavy metals concentration, the HI was calculated using USEPA Equation 3.

$$HI =$$

$$HQ_{Sr} + HQ_{As} + HQ_{Sb} + HQ_{Ba} + HQ_{Zn} + HQ_{Mn} \dots(3)$$

After calculation HI was then compared to the standards value of USEPA. If the value shows greater than 1, there is a possibility of non-carcinogenic impacts occurring in the residents. Lower value represents unlikely that the

exposed individual has obvious harmful health effects from heavy metals (Dorne *et al.*, 2011).

Carcinogenic risk analysis: Literature indicates that the assessment of the potential cancer risk associated with heavy metals can be calculated using the following equation (Mohammadi *et al.*, 2019; Saleh *et al.*, 2019);

$$ILCR = CDI \times CSF \dots\dots\dots(4)$$

Where, ILCR refers to Incremental Lifetime Cancer Risk and the term CSF refers to the cancer slope factor, which represents the risk related with an average lifetime exposure to one milligram per kilogram per day of a cancer-causing chemical. The permissible limits for a single carcinogenic element and multiple-element carcinogens are set at 10⁻⁶ and less than 10⁻⁴ respectively (Maleki & Jari, 2021).

RESULTS AND DISCUSSION

The physiochemical parameters were determined in this study which ranged; pH (6.9-7.4), TDS (155-304 ppm), EC (322-630 µS/cm), chlorides (28.4-78.1 mg/l), carbonates (24-120 mg/l), bicarbonates (61-427 mg/l) where, S1 EME filter showed highest value of pH as compared to other areas. On the other hand, bicarbonates are high in S3H bore water area (Figure 2 and 3). The metals detected; Calcium (19.36-52.31 mg/l), Magnesium (11.49-25.78 mg/l), Sodium (0.11-148 mg/l), Potassium (0.7-11.28 mg/l), Silicon (8.54-12.19 mg/l) (Figure 4). The trace toxic metals detected via ICP-OES technique were As, Sb, Sr, Zn, Mn and Ba.

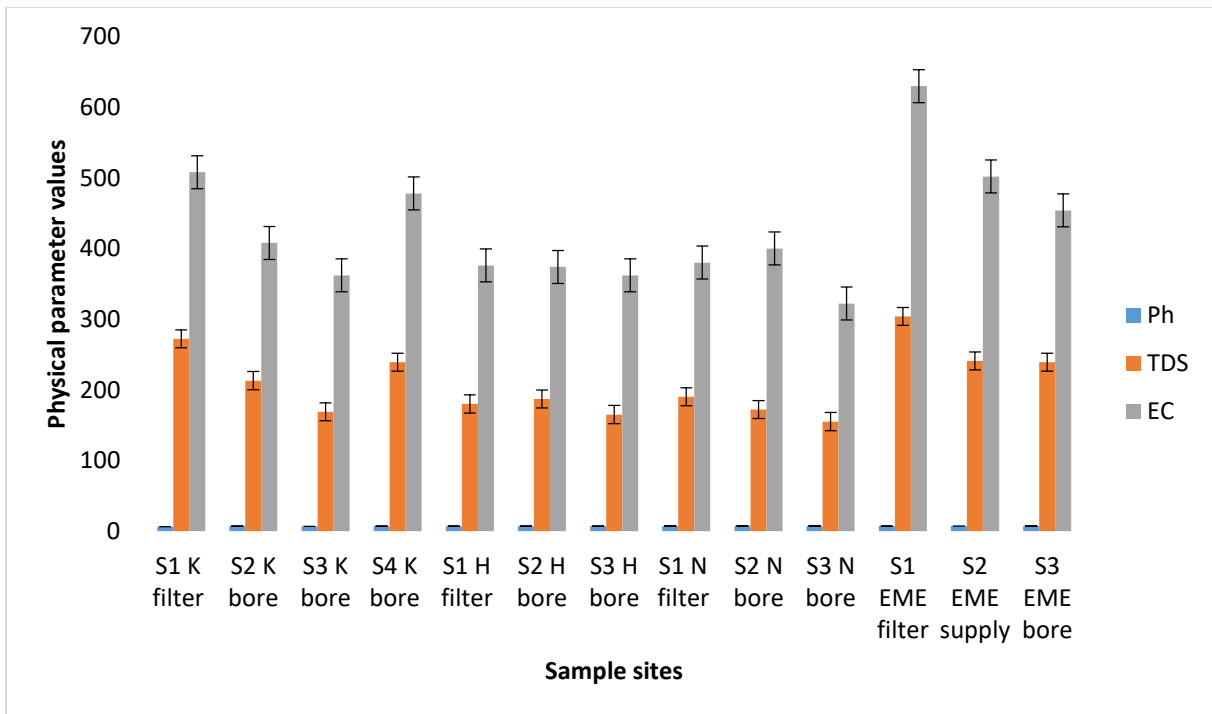


Figure 2. Physical parameters of sampling water

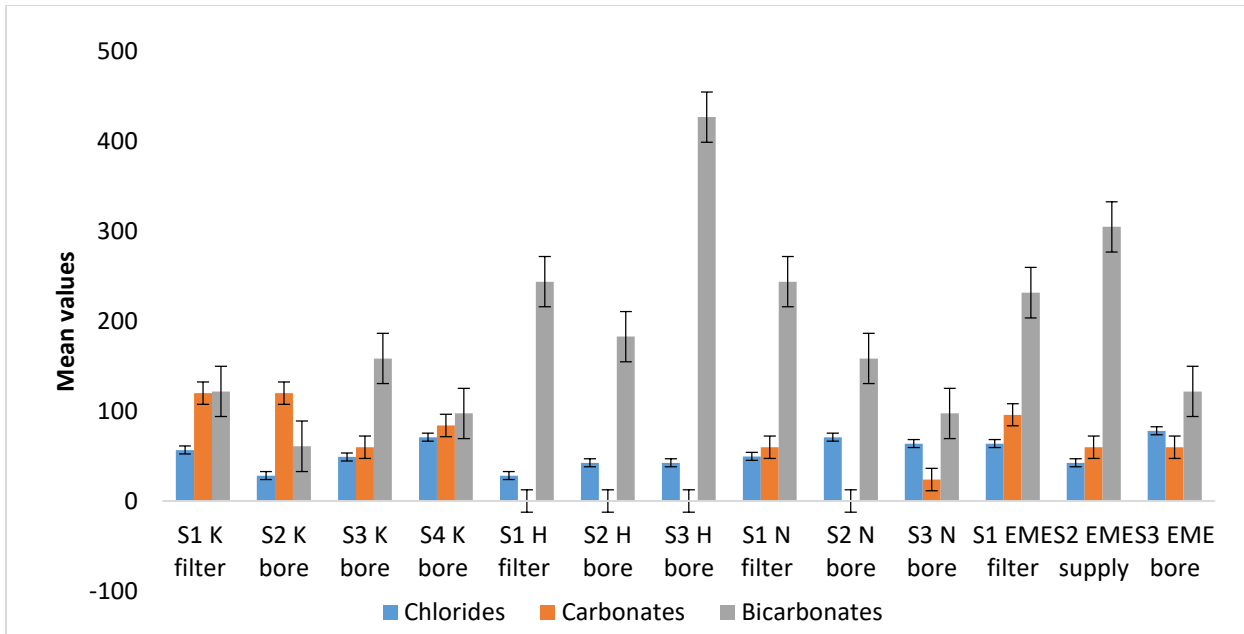


Figure 3. Mean of chemical properties of all samples from selected areas (concentration of chlorides, carbonates and bicarbonates)

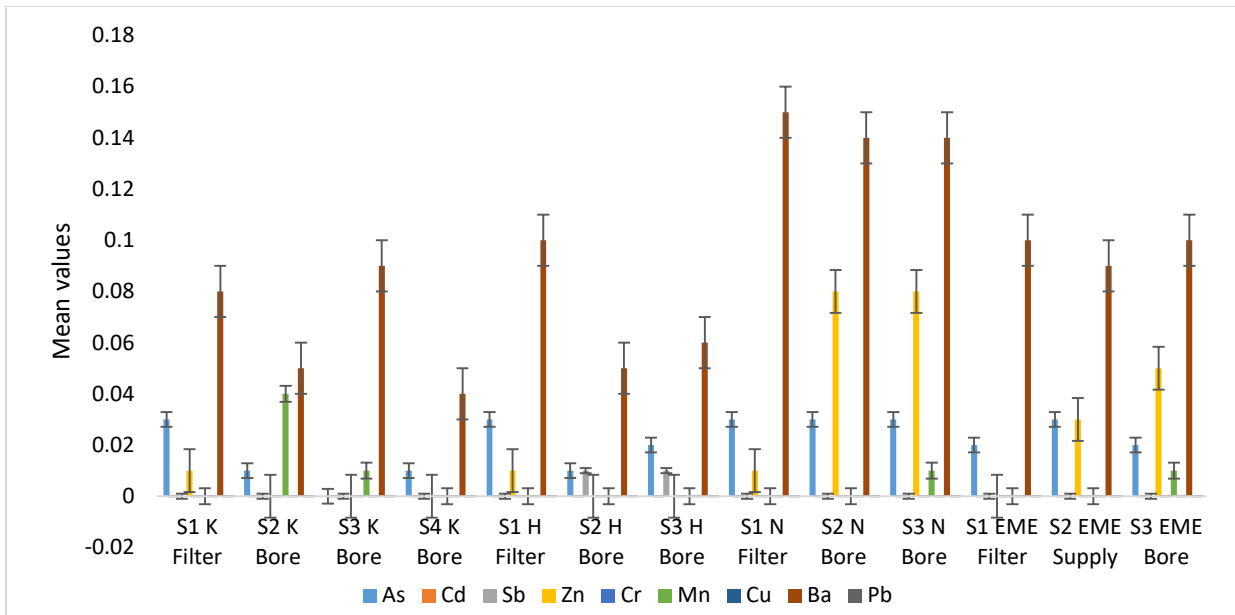


Figure 4. Mean values of selected of toxic heavy metals

Figure 4 represents the mean values of well water and filtered water from selected areas, where S1N filter values are high in terms of Ba. The arsenic concentration ranged from 0.01 mg/l – 0.03 mg/l that was lower than the PEQ standard of 0.05mg/l but exceeds the permissible limits of WHO (0.01 mg/l). This indicates that some water samples exceed the permissible limit which could be harmful to one’s health over time. Groundwater contamination with arsenic is mostly geogenic originated from naturally occurring geological

resources. Arsenic is commonly released into groundwater in South Asian countries including Pakistan, India and Bangladesh from arsenic alluvial sediments and sedimentary rocks (Smedley & Kinniburgh, 2002).

Epidemiological research indicates that long term exposure to arsenic in drinking water even at low level has been shown to raise blood pressure and cardiovascular risk (Chen *et al.*, 2011; Zhang *et al.*, 2013). Since arsenic is one of the most hazardous trace elements in drinkable water, the presence of arsenic over

the recommended level suggests a possible concern even though the exceedance was not very large. The concentration of Antimony, Strontium, Barium, Zinc and

Manganese ranged from 0.01, 0.33-0.53, 0.04-0.15, 0.01-0.08 and 0.01-0.04 mg/L respectively (Table 3).

Table 3. Mean concentrations of physical parameters and toxic metals

Parameter (µS/cm) / (mg/l)	Minimum	Maximum	Mean	WHO Standards	Pakistan Standards
pH	6.9	7.4	7.007	6.5-8.5	6.5-8.5
Electrical Conductivity	322	630	427.38	400	200-800
TDS	155	304	209.69	<1000	<1000
Chlorides	28.4	78.1	52.97	250	<250
Carbonates	24	120	52.61	600	600
Bicarbonates	61	427	188.63	500	500
Calcium	19.36	52.31	28.96	100-300	100
Magnesium	11.49	25.78	15.99	≥30	150
Sodium	0.11	148	103.76	270	200
Potassium	0.7	11.28	4.383	12	12
Barium	0.04	0.15	0.091	0.7	0.7
Silicon	8.54	12.19	10.6825	–	–
Arsenic	0.01	0.03	0.02	0.01	≤0.05
Zinc	0.01	0.08	0.0385	3	5
Antimony	0.00	0.01	0.01	0.02	≤0.005
Strontium	0.33	0.53	0.42	1.5	–
Manganese	0.01	0.04	0.0175	0.5	≤0.5

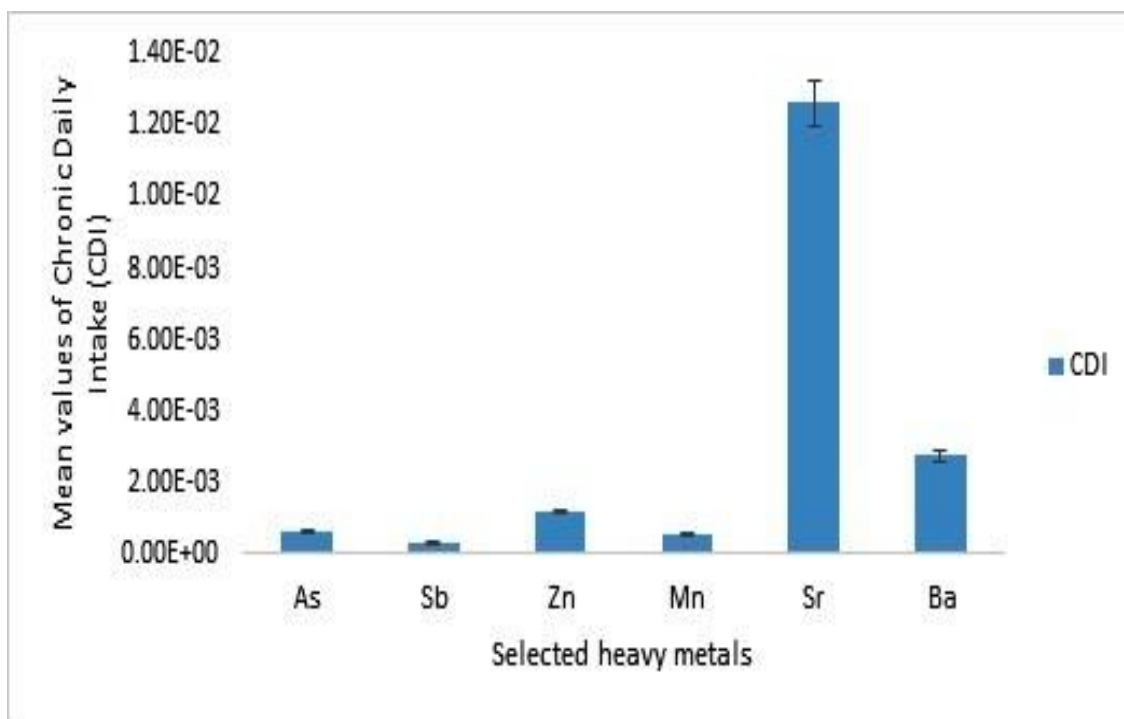


Figure 5. CDI values of the toxic trace metals

Figure 5 represents the Chronic Daily Intake (oral) mean values of Arsenic, Antimony, Strontium, Barium, Zinc and Manganese ranged from 0.0003 – 0.0009, 0.0-0.0003, 0.001-0.0159, 0.0012- 0.0045, 0.0003-0.0024 and 0.0003-0.0012 respectively. Oral HQ

(Hazard Quotient) for Sr, As, Sb, Ba, Zn and Mn ranged from 0.00166-0.0265, 1.00-3.00, 0.00-0.75, 0.0171-0.064, 0.001-0.008 and 0.00214-0.00857 respectively (Figure 6). Only HQ above one has potential risk on human health, less than one has no hazard. In all these

toxic metals, the concentration is too low to cause risk on human health except Arsenic, which has HQ of 1.00-3.00 indicates that long term exposure may pose serious health concerns.

The sum of HQ of all metals ranged from 1.0001-3.929. Incremental Lifetime Cancer Risk (ILCR) for arsenic is ranged from 0.00045-0.00135 (Table 4).

The Cancer Risk is measured in millions (X in millions are prone to cancer). In this context, 450-1350

individuals in a million are chronically exposed to arsenic and posing cancer risk. Meta-analysis of 51 research studies indicates that there is a definite dose-response association between arsenic exposure and lung cancer even at low to moderate levels (Dummer *et al.*, 2024). Moreover, according to meta-analysis of 30 years' worth of epidemiological research, drinking arsenic contaminated water is connected to a high risk of kidney and bladder cancer (Saint-Jacques *et al.*, 2014).

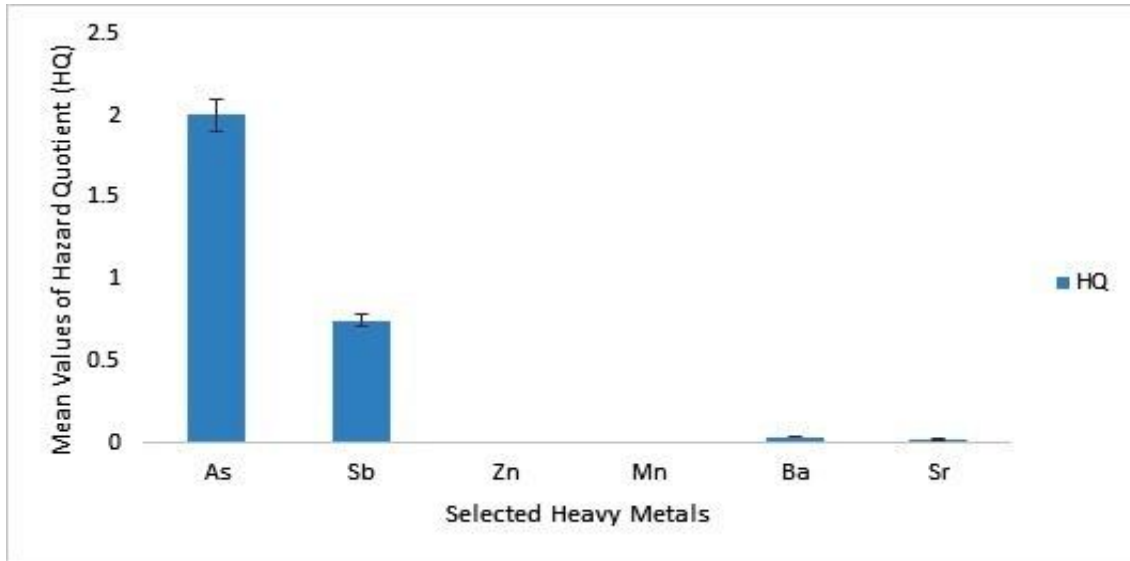
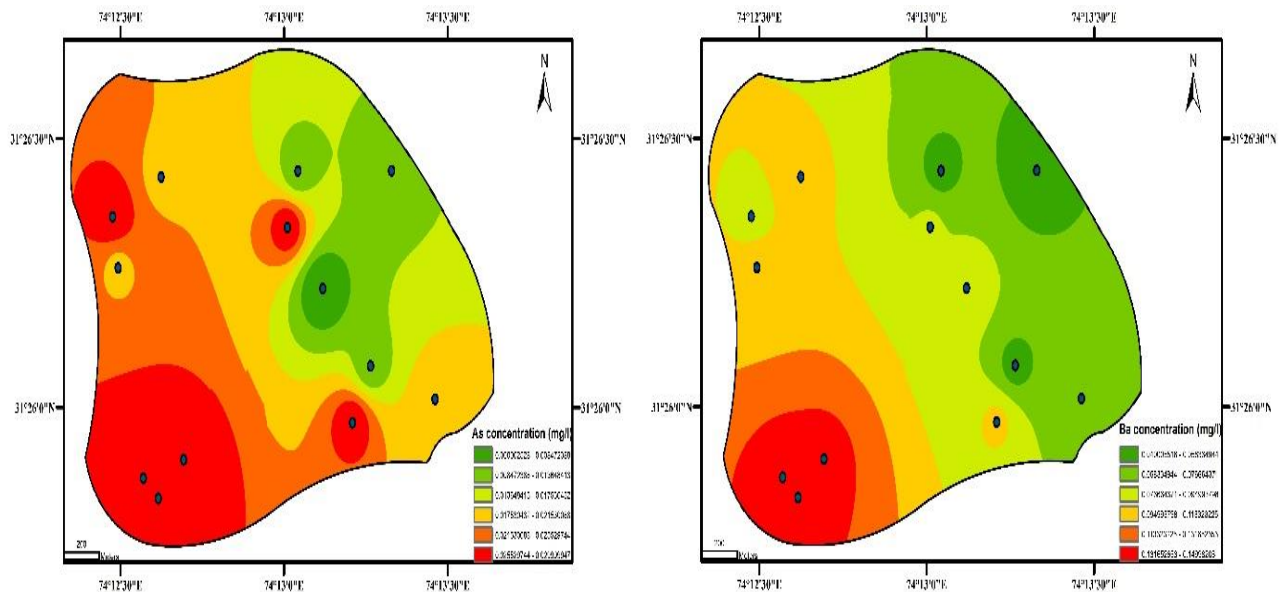


Figure 6. Mean values of Hazard Quotient (HQ)

Table 4. Mean values of Hazard Index and ILCR of Arsenic

Index	Minimum	Maximum	Mean
Hazard Index	1.00652	3.92935	2.8176
ILCR (for Arsenic)	4.5E-04	1.35E-03	9E-04



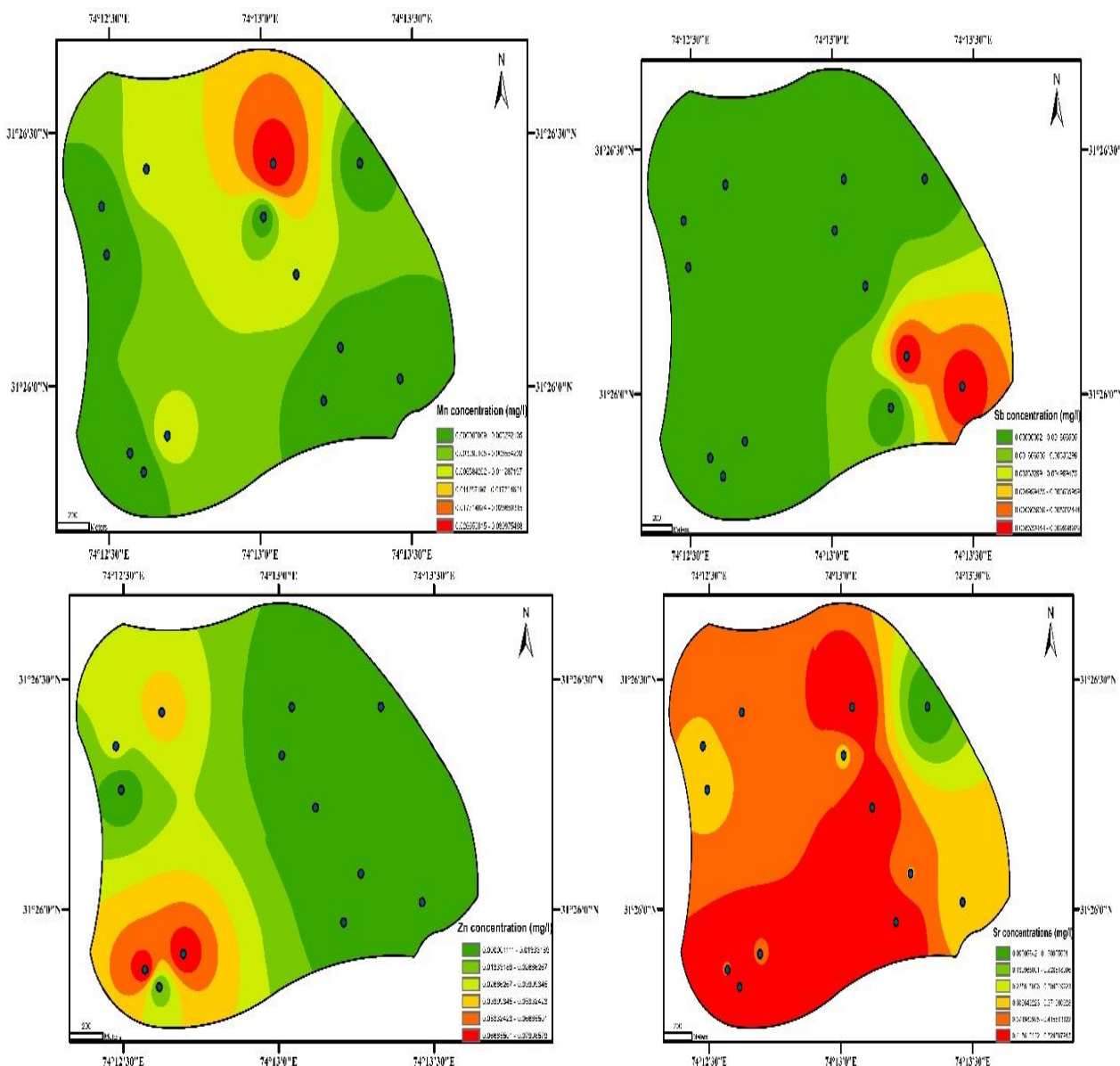


Figure 7. Spatial analysis of concentration of trace metals As, Sb, Zn, Sr, Ba and Mn.

Overall outcomes of the research represent the safe utilization of drinking water regardless of tap and filtered water except arsenic health risk. Figure 7 has shown the spatial distribution of all selected heavy metals which clearly indicates the exposure and health hazard of pollution in drinking water (Figure 7). Due to its cumulative toxicity and carcinogenic tendency, the presence of arsenic even at relatively low concentration poses possible long term health risks.

Conclusions: The physical parameters determined in this study ranged; pH (6.9-7.4), TDS (155-304 ppm), EC (322-630 μ S/cm), chlorides (28.4-78.1 mg/l), carbonates (24-120 mg/l), bicarbonates (61-427 mg/l). The samples were collected from filters installed by government for

public water consumption and direct groundwater source. The chemical and physical parameter values for all samples were more or less similar. It is evident that the water from filters by government are not much cleaner than the direct groundwater source. It is recommended that the quality of these filters must be checked and properly maintained properly by government itself. The metals detected; Calcium (19.36-52.31 mg/l), Magnesium (11.49-25.78 mg/l), Sodium (0.11-148 mg/l), Potassium (0.7-11.28 mg/l), Silicon (8.54-12.19 mg/l). These metals are essential but their much-exceeded limit can cause health hazards. In present study, the metals are under the recommended limit by WHO and Pak Standards. The trace toxic metals detected via ICP-OES technique were As, Sb, Sr, Zn, Mn and Ba. Arsenic concentrations

varied from 0.01 mg/l to 0.03 mg/l, with some samples exceeding the allowable limit of 0.01 mg/l. The concentration of Antimony, Strontium, Barium, Zinc and Manganese ranged from 0.01, 0.33-0.53, 0.04-0.15, 0.01-0.08 and 0.01-0.04 mg/L respectively. Chronic Daily Intake (oral) was calculated using US EPA equations for Sb, Sr, As, Mn, Zn and Ba in mg/kg/day. Oral CDI of Arsenic, Antimony, Strontium, Barium, Zinc and Manganese ranged from 0.0003 – 0.0009, 0.0-0.0003, 0.001-0.0159, 0.0012- 0.0045, 0.0003-0.0024 and 0.0003-0.0012 respectively. Oral HQ (Hazard Quotient) for Sr, As, Sb, Ba, Zn and Mn ranged from 0.00166-0.0265, 1.00-3.00, 0.00-0.75, 0.0171-0.064, 0.001-0.008 and 0.00214-0.00857 respectively. Only HQ above one has potential risk on human health, less than one has no hazard. In all these toxic metals, the concentration is too low to cause risk on human health except Arsenic that has HQ of 1.00-3.00. Hazard index, sum of hazard quotients of all metals ranged from 1.0001-3.929. Incremental Lifetime Cancer Risk for arsenic is ranged from 0.00045-0.00135. It was concluded that public of this rural area was safe from hazards of trace metals except arsenic that posed a low risk to public. However, a small amount of exposure to arsenic for a very long time (chronic) may be the cause of cancer, skin lesions, cardiovascular and neurological effects. In Pakistan, the major source of arsenic in groundwater is geogenic release, which is natural. The natural sources cannot be eliminated for risk management of Arsenic, however, it is suggested that public should not consume water from direct groundwater source. Rather proper filters for public should be installed that ensures the safety from this carcinogenic metal. To prevent chronic health effects, regular monitoring and arsenic-removal treatments are advised.

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