Iqbal *et al. Environmental Sciences Europe* (2024) 36:9
https://doi.org/10.1186/s12302-023-00824-2

Environmental Sciences Europe

RESEARCH **Open Access**

Human health and ecology at risk: a case study of metal pollution in Lahore, Pakistan

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Abstract

Background With rapid industrial development, heavy metal contamination has become a major public health and ecological concern worldwide. Although knowledge about metal pollution in European water resources is increasing, monitoring data and assessments in developing countries are rare. In order to protect human health and aquatic ecosystems, it is necessary to investigate heavy metal content and its consequences to human health and ecology. Accordingly, we collected 200 water samples from different water resources including groundwater, canals, river and drains, and investigated metal contamination and its implications for human and ecological health. This is the first comprehensive study in the region that considered all the water resources for metal contamination and associated human health and ecological risks together.

Results Here we show that the water resources of Lahore (Pakistan) are highly contaminated with metals, posing human and ecological health risks. Approximately 26% of the groundwater samples are unsuitable for drinking and carry the risk of cancer. Regarding dermal health risks, groundwater, canal, river, and drain water respectively showed 40%, 74%, 80%, and 90% of samples exceeding the threshold limit of the health risk index (HRI > 1). Regarding ecological risks, almost all the water samples exceeded the chronic and acute threshold limits for algae, fish, and crustaceans. Only 42% of groundwater samples were below the acute threshold limits. In the case of pollution index, 72%, 56%, and 100% of samples collected from canals, river Ravi, and drains were highly contaminated.

Conclusions In conclusion, this comprehensive study shows high metal pollution in water resources and elucidates that human health and aquatic ecosystems are at high risk. Therefore, urgent and comprehensive measures are imperative to mitigate the escalating risks to human health and ecosystems.

Keywords Heavy metals, Human health, Ecology, Risk assessment, Drinking water contamination, Surface water contamination

Background

Heavy metal contamination has become a global ecological and public health concern [1–3], particularly due to persistence and higher toxicity [4–6]. Pakistan is one of the developing countries facing water scarcity and metal contamination, and therefore, struggling with both quantity and quality issues [7–9].

Rapid population growth, urbanization, industrialization and agricultural activities put great pressure on both the quantity and quality of water resources. Misuse of water resources, non-compliance with pollution standards and disposal of untreated effluents into freshwater resources are common practices [10], which may

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increase water scarcity, and health and ecological consequences. The situation is even worse in urban areas where sewerage water directly enters into canals and rivers. Besides direct disposal, atmospheric, anthropogenic and geogenic chemical pollutants trickle down into the groundwater basin in the process of recharging the aquifer through precipitation [11]. In addition, saltwater intrusion, and leakage of septic tanks and landfills also lead to groundwater contamination [12]. As a result, surface water quality is deteriorating and not suitable for drinking and agricultural usage [13–15]. Various studies and surveys have reported increased water pollution especially in big cities of Pakistan [15, 16]. Some studies have also reported the accumulation of heavy metals in soil irrigated with contaminated canal water [17, 18]. As a consequence of widespread metal contamination, water-borne diseases have become very common in Pakistan, constituting about 80% of total diseases and about 30% of deaths [19]. Due to the continuous use of contaminated water, people are at a high risk of cancer, birth defects, post-neonatal mortality, and other chronic diseases [20, 21]. Therefore, it is necessary to regularly monitor the water quality of all major water bodies to design the appropriate mitigation strategies.

Although, several studies have investigated heavy metal contamination in groundwater [21, 22], canals [23, 24], rivers [25, 26], and drains [27, 28] separately, none of the studies considered all these water resources together, and focus on human health and ecology. We hypothesized that the metal contamination of water resources in Lahore might pose both human health and ecological risks. Here we report the first comprehensive study in the region that considered all the water resources for metal contamination and associated human health and ecological risks.

In the present study, we aimed at monitoring the heavy metals (Cu, Cr, Ni and Pb) contamination in groundwater, canals, river Ravi, and drains of Lahore, Pakistan. Although there are several toxic metals in the environment, we focused on these four metals due to their well documented health [29, 30] and ecological impacts [31], and association with local urban and industrial activities [29, 32]. Focusing on these heavy metals ensures compliance with regulations and efficient resource allocation to address potential risks to public health and the environment. We further aimed at analyzing the human health and ecological risks associated with metal contamination in terms of (i) health risk index (HRI) for children, females and males, (ii) toxic pressure (TU) and risk quotient (RQ) for aquatic organisms and (iii) pollution index (PI).

Methods

Description of the study sites and sampling

The current study was conducted in Lahore, the second-largest metropolitan city in Pakistan. It is ranked as the 18th most populous city in the world with an 11.13 million total population and 6300 persons/km^2 population density according to the Census of 2017 [33]. The sampling sites were identified with a global positioning system (GARMIN eTrex 30) and a field survey was carried out. A total of 200 water samples were collected from various sources, including 50 each from groundwater, canals, river, and drains (Fig. 1, Additional file 1: Table S1). The rainfall events are suggested to have the potential to alter the metal contamination of water [34]. To rule out the impact of rainfall events, samples were collected from March to April 2019 using a grab sampling technique. Thus, we mainly focused on metal contamination of dry season. Briefly, groundwater samples were collected from 50 tube wells located across the city. For canal water, samples were collected from the Lahore canal and BRB canal (Bambawali-Ravi-Bedian). For the river, all the samples were collected from river Ravi, from Syphon to Sagian pull in the downstream direction. For wastewater, major polluted drains were selected such as Hudiara drain (20 sites), Cantt drain (20 sites), and Sattukatla drain (10 sites). A minimum distance of 1 km was maintained between every two sampling sites. A detailed description of sampling sites is provided in supporting information (Additional file 1: Table S1).

Samples were collected during the daytime between 8 a.m. to 4 p.m. with the help of pre-washed buckets and transferred to 1 L glass containers. To avoid any contamination, each container was placed into a zip-lock polythene bag and transported to the lab for preservation and analysis. Samples were stored at $-4\ ^0$C until analyzed. Physico-chemical parameters such as pH, temperature, EC, and TDS were recorded with multi-meter (EUTECH instruments PC510) at each site (Additional file 1: Table S2).

Sample analysis

Samples were analyzed following the “Standard Methods for the Examination of Water and Wastewater” by the American Public Health Standard Association, 21st edition [35]. Briefly, the samples were subjected to filtration using a 0.45 μm filter. Additionally, we added 10 mL of nitric acid (HNO_3) to the samples to prevent any heavy metal precipitation. The analysis of Cu, Cr, Ni, and Pb was carried out at the Irrigation Department, Lahore, Punjab through atomic absorption spectroscopy using an equipment Varian FS 240AA (Varian Medical Systems, Palo Alto, CA, USA). For quality assurance, standard reference materials

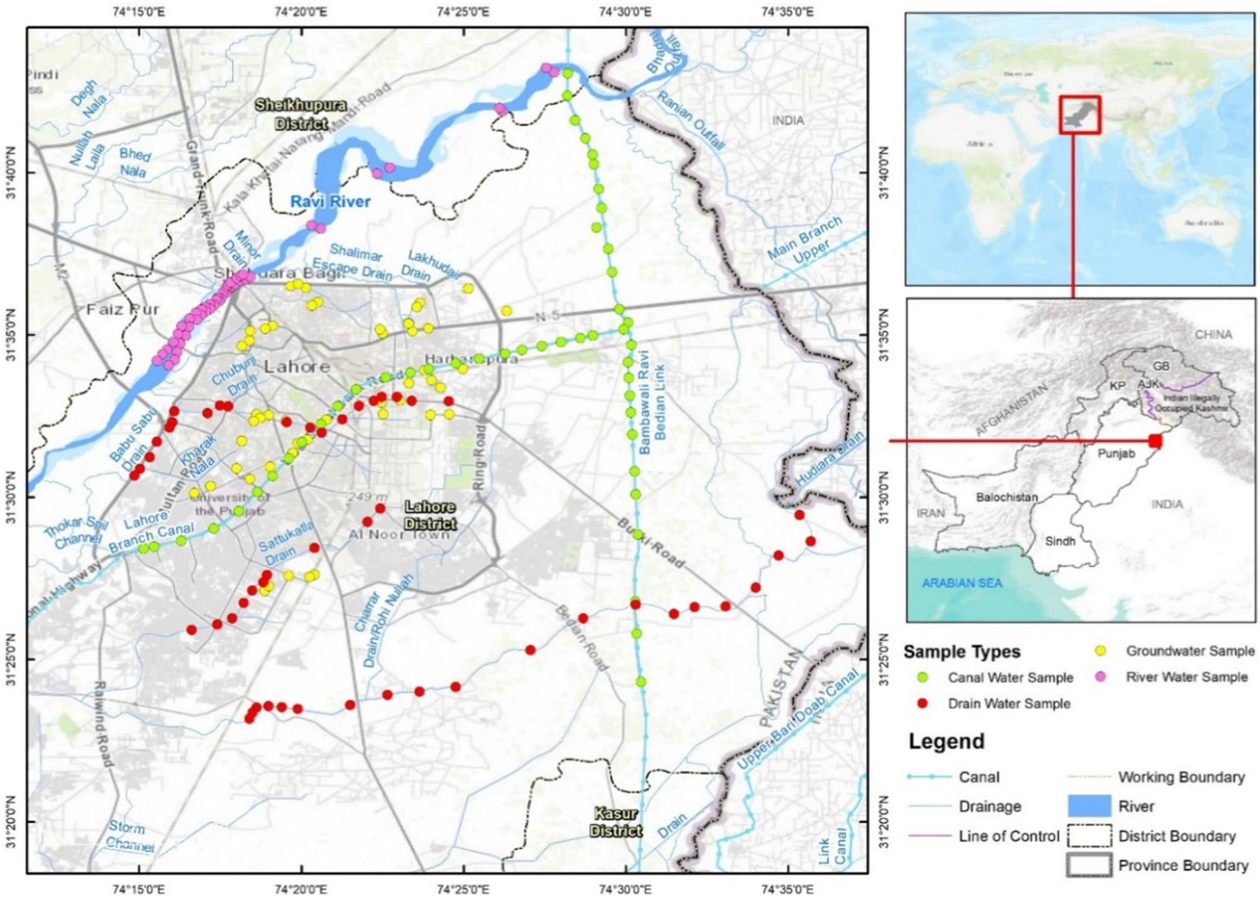

Fig. 1 Location of the sampling sites from different water resources of Lahore. Circles represent the sampling sites and are colored according to the type of samples (groundwater: yellow, canal water: green, river water: pink, and drain water: red)

from the National Institute of Standards and Technology (NIST) were used. The relative standard deviation of analytical procedures ranged from 5 to 10%. The analysis was conducted thrice and the average value was used for statistical evaluation.

Human health risk assessment

Human health risk assessment for heavy metals was calculated by considering oral and dermal exposures. The potential hazard for each metal was calculated by Chronic Daily Intake (CDI) and Hazard Quotient (HQ). For CDI, we used the following equations suggested by the Agency for Toxic Substances and Disease Registry [36].

$$\mathrm{CDI_{Oral}} = \frac{(\mathrm{C} \times \mathrm{IR} \times \mathrm{EF})}{\mathrm{BW}}, \tag{1}$$

$$\mathrm{CDI_{Dermal}} = \frac{(\mathrm{C} \times \mathrm{SA} \times \mathrm{ET} \times \mathrm{P} \times \mathrm{CF})}{\mathrm{BW}}, \tag{2}$$

where C is the concentration of metal, IR is the intake rate of water, ET is exposure time, EF is the exposure factor, CF is the conversion factor, P is the permeability coefficient, SA is the total surface area of skin, and BW is body weight. The average values of EF, ET, IR, SA, P, CF, and BW are provided in the supporting information (Additional file 1: Table S2). The body weight (BW) was calculated for adults aged between 15–67 years for females, 15–66 years for males, and 0–15 years for children [30, 37]. Similarly, the average value of skin surface area for adults is 18,450 cm^2 and for children is 16,450 cm^2. Furthermore, the non-carcinogenic effects of metals were calculated by using HQ (Eq. 3).

$$\mathrm{HQ} = \frac{\mathrm{CDI}}{\mathrm{RfD}}. \tag{3}$$

Reference dose (RfD) values for oral and dermal exposure pathways are provided in supporting information (Additional file 1: Table S3). The HQ < 1 shows the concentration of metal does not produce carcinogenic effects.

Health risk index (HRI) was calculated by adding all HQ (Eq. 4). Oral and dermal health risk index was calculated for each site as well as for different population groups e.g. children, males, and females.

$$\mathrm{HRI} = \sum \mathrm{RQ}. \tag{4}$$

Ecological risk assessment

We analyzed the ecological risk of metal contamination based on the toxic unit (TU) for three trophic levels i.e., algae, fish and crustaceans [38] (Eq. 5). The toxic unit is defined as the ratio of measured concentration (for metals) and effect concentration (lethal and sub-lethal) for three organisms (algae, fish and crustaceans). Reference values for EC_{50} or LC_{50} were obtained from previous studies [39–44] and are provided in supporting information (Additional file 1: Table S4).

$$\mathrm{TU}_{\mathrm{sum}} = \log\left[\sum_{i=1}^{n}\left(\frac{\mathrm{Ci}}{\mathrm{LC}_{50\mathrm{i}}}\right)\right], \tag{5}$$

where TU_{sum} is the sum of the effect of "n" metals detected at each site, Ci is the concentration (μg/L) of the respective metal "i", and LC_{50i} is the median lethal concentration (μg/L) of that metal for the reference organisms.

Further, the risk quotient (RQ) was calculated to assess the ecological risk for aquatic organisms. RQ is the ratio of the measured environmental concentration (MEC) of metals and predicted no-effect concentration (PNEC). The PNEC values were obtained from a previous study [45] and the NORMAN Ecotoxicology Database [46]. RQ_{sum} was calculated using the following equation.

$$\mathrm{RQ}_{\mathrm{sum}} = \sum_{\mathrm{i}=1}^{\mathrm{n}}\left[\frac{\mathrm{MEC}_{\mathrm{i}}}{\mathrm{PNEC}_{\mathrm{i}}}\right], \tag{6}$$

where RQ_{sum} is the sum of the risk of n metals detected at each site, MECi is the measured environmental concentration of respective metal "i", and PNECi is the predicted no-effect concentration of respective metal "i" at each site.

Water pollution index

To compare metal concentration in different matrices, we calculated the pollution index (PI) by dividing metal concentration by its permissible limits, and then taking the average of all metals (Eq. 7).

$$\mathrm{PI} = \frac{\frac{\mathrm{Cu}}{2000} + \frac{\mathrm{Cr}}{50} + \frac{\mathrm{Ni}}{20} + \frac{\mathrm{Pb}}{10}}{4}, \tag{7}$$

where $PI > 1$ indicates that metal concentrations are above the permissible limit and can cause hazards. PI was classified as low ($PI \leq 1$), moderate ($1 < PI \leq 3$) and highly polluted ($PI > 3$) [47].

Data analysis

For statistical analyses and figures, we used RStudio version 2022.2.3.492 for Windows [48] and the basic R version 4.2.1 for Windows [49]. A spatial map was produced in ARC Map, ArcGIS V. 10.1 (ESRI 2012).

Results

Heavy metal contamination

Overall, water samples collected from all resources showed heavy metal contamination. Approximately 61% of the water samples exhibited contamination with all four metals, 31% with three metals, 8% with two metals, and less than 1% with one metal. More specifically, 42% of the groundwater samples exceeded the permissible limits for drinking water set by the World Health Organization (WHO) (Fig. 2; Additional file 1: Table S5). Among different metals, Pb frequently surpassed the WHO permissible standards followed by Cr and Ni. In general, the trend of metal contamination (μg/L) in groundwater samples was as follows: Cr > Pb > Cu > Ni. Furthermore, none of the water samples collected from canals, river, and drains were deemed suitable for drinking. Among surface water samples, approximately 98% (147 of 150) exceeded the water quality standards set by the World Health Organization (WHO). The metal concentrations detected in river and drains followed a consistent trend: Cu > Cr > Ni > Pb. However, in canals, Ni concentrations were higher than Cr, slightly altering the trend to Cu > Ni > Cr > Pb. Notably, the average concentration of Cu was consistently high in all surface water bodies, with drains showing two to threefold higher concentrations than river and canals (Additional file 1: Table S5). In most of the cases, Cr and Ni were exceeding the permissible limits.

To identify insightful patterns and relationships within the data, we applied Principal Component Analysis (PCA). The first two components of PCA explained 82.4% of the total variance (Additional file 1: Fig. S1). PC1 explained 70.3% of the total variance and showed maximum loadings on Cr and Cu. PC2 explained 12.1% of the variance, with maximum loading on Ni.

Health risk assessment

To evaluate drinking water quality, we calculated the Health Risk Index (HRI) for two major exposure

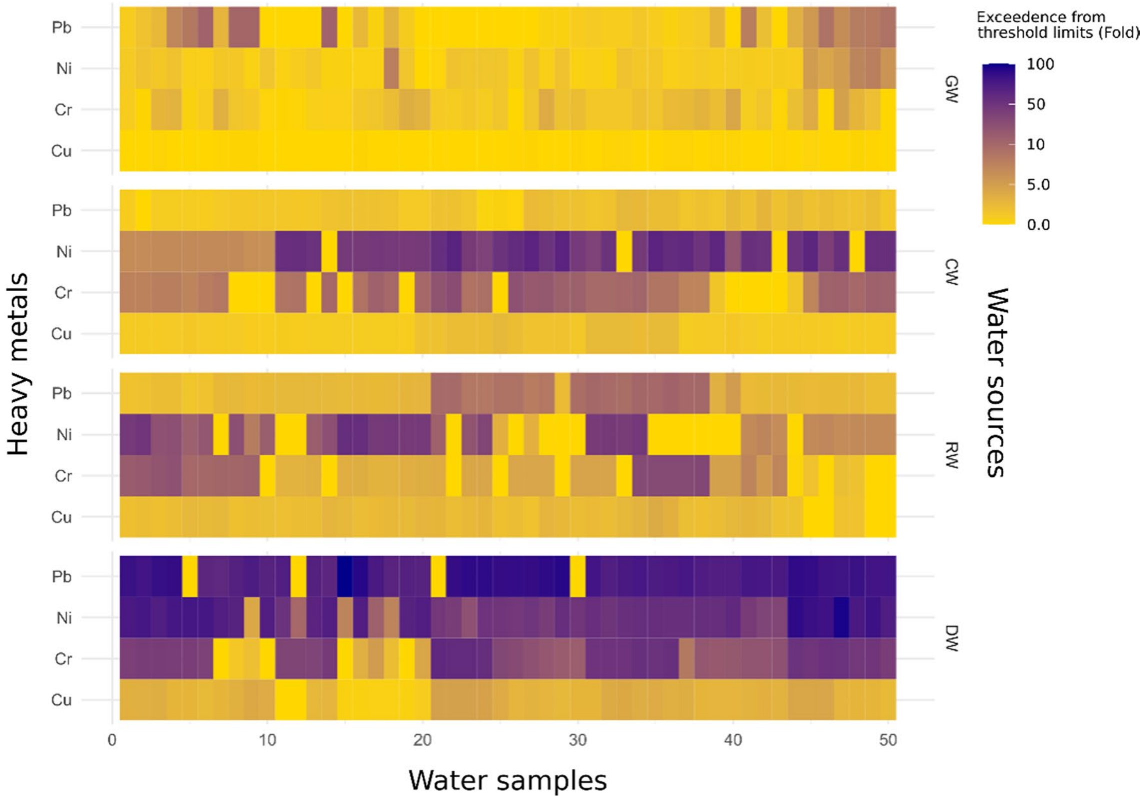

Fig. 2 Spatial heat map showing metal concentrations exceeding the threshold limits. The exceedance is calculated as the ratio between the detected concentration and the permissible limits set by the World Health Organization (WHO). Values are presented for water samples collected from groundwater (GW), canals (CW), river (RW) and drains (DW)

pathways such as ingestion (oral) and absorption through skin (dermal). For the potential health risks associated with the ingestion of metals, we considered only groundwater samples. Overall, 26% of groundwater samples exceeded the threshold limit for oral intake (Fig. 3, Additional file 1: Table S6), with HRI_{oral} ranging from 0 to 2.5, mainly due to higher concentrations of Cr. Results of the dermal health risk index (HRI_{dermal}) revealed that 71% (142 out of 200) of the water samples were deemed unfit, with Cr as the main cause of dermal risk (Fig. 4). Specifically, 40% of groundwater samples, 74% of canal water samples, 80% of river water samples, and 90% of drain water samples had the potential to cause dermal health risks with HRI_{dermal} values up to 4.3, 36.4, 43.3, and 87, respectively.

Ecological risk

To characterize heavy metal contamination, we calculated toxic units assuming concentration addition ($logTU_{sum}$, see methods). All the water resources were highly contaminated with heavy metals. Overall, 88% of samples were exceeding the acute threshold limits. The least contamination was detected in groundwater samples (Fig. 5, Additional file 1: Table S7). The toxic unit ($logTU_{sum}$) ranged from − 2.04 to − 0.04 for algae, − 1.91 to 0.174 for crustaceans, and − 3.81 to 0.1 for

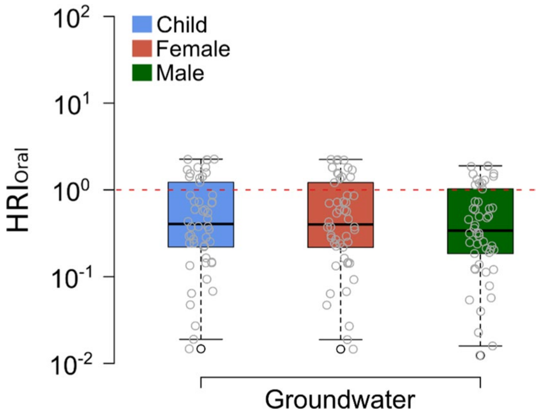

Fig. 3 Health risk of metal contamination through ingestion. Oral Health Risk Index values are presented for groundwater samples. The boundaries of the central box are the 25th and 75th percentiles; the horizontal line is the median; and the whiskers of the boxplot represent the minimum and maximum values. The Red dashed line represents the threshold limit for oral health risk

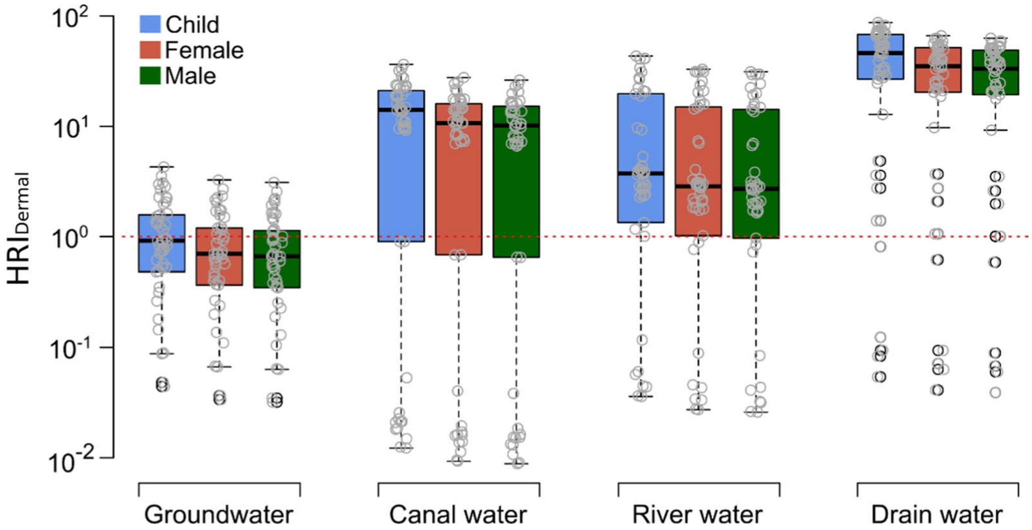

Fig. 4 Health risk of metal contamination through dermal contact. Dermal Health Risk Index values are presented for different water sources including groundwater samples, canals, and river and drain water samples. The boundaries of the central box are the 25th and 75th percentiles; the horizontal line is the median; and the whiskers of the boxplot represent the minimum and maximum values. The Red dashed line represents the threshold limit for dermal health risk

fish. For canal water, the TU_{sum} ranged from 0.15 to 1.07 for algae, 0.57 to 1.22 for crustaceans, and 0.36 to 0.96 for fish. River water was slightly less contaminated as compared to canal and drain. The TU_{sum} ranged from – 2.9 to 1.03 for algae, – 0.5 to 1.41 for crustaceans and 0.64 to 0.8 for fish. Drain water was highly contaminated with heavy metals, and toxic units ($logTU_{sum}$) ranging from 0 to 1.3 for algae, – 1.1 to 1.35 for crustaceans, and – 1.2 to 2.0 for fish.

The metal concentrations were also transformed into risk quotients (RQ) by dividing the detected concentrations by the corresponding threshold values. Furthermore, RQ_{sum} was calculated by summing the risks caused by individual metals at each site. Overall, all the water samples showed higher RQ_{sum} (Fig. 6), indicating a higher risk for aquatic organisms. The RQ_{sum} ranged from 0.9 to 88 for groundwater, 71 to 637 for canals, 23 to 759 for river and 348 to 1905 for drains (Additional file 1: Table S8). In different water resources, different metals were responsible for the higher RQ_{sum}. For example, in more than half of the groundwater samples, Cr caused a higher risk. In the case of canals, Ni and Cu showed

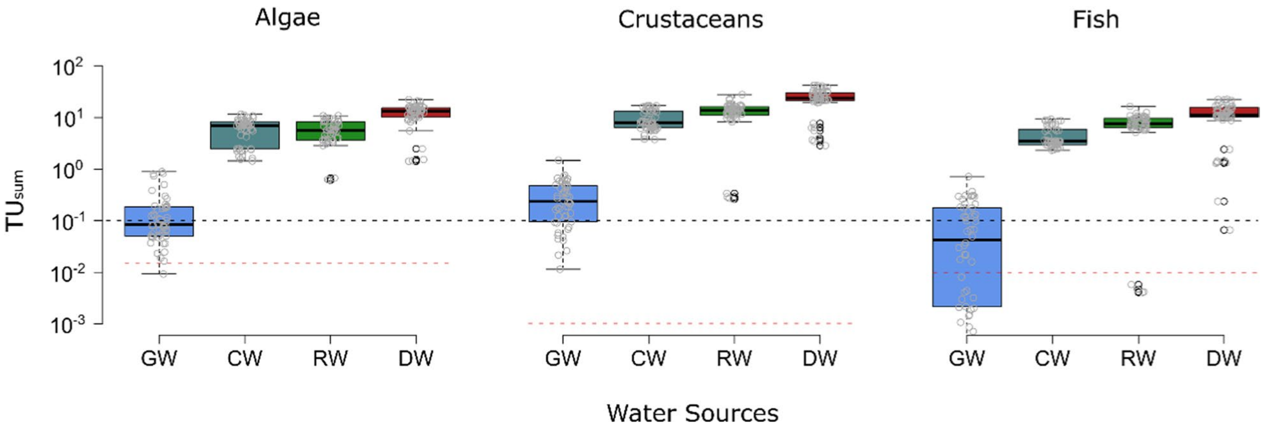

Fig. 5 Characterization of metal contamination. The toxic units (TU_{sum}) are presented for different water resources including groundwater (GW: blue), canal water (CW: cyan), river water (RW: green) and drain water (DW: red). For the calculation of Toxic Units, we used LC_{50} or EC_{50} of algae, crustaceans and fish. The boundaries of the central box are the 25th and 75th percentiles; the horizontal line is the median; and the whiskers of the boxplot represent the minimum and maximum values. The black dashed line indicates the threshold limit for acute risks for algae, crustaceans and fish, whereas, the red dashed lines represent the threshold limit for chronic risks

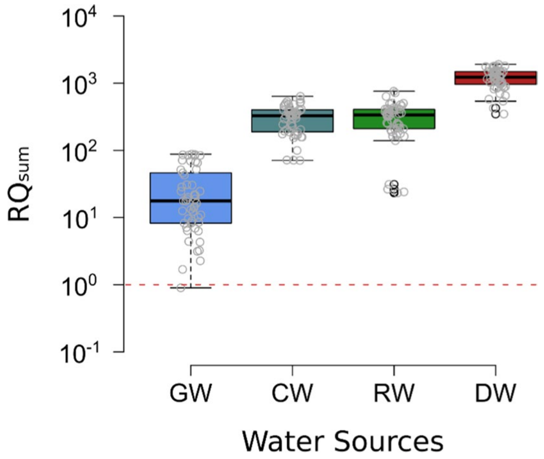

Fig. 6 Characterization of ecological risk. The sums of risk quotients (RQ_{sum}) are presented for different water resources including groundwater (GW: blue), canal water (CW: cyan), river water (RW: green) and drain water (DW: red). The boundaries of the central box are the 25th and 75th percentiles; the horizontal line is the median; and the whiskers of the boxplot represent the minimum and maximum values. The Red dashed line represents the threshold limit for the risk

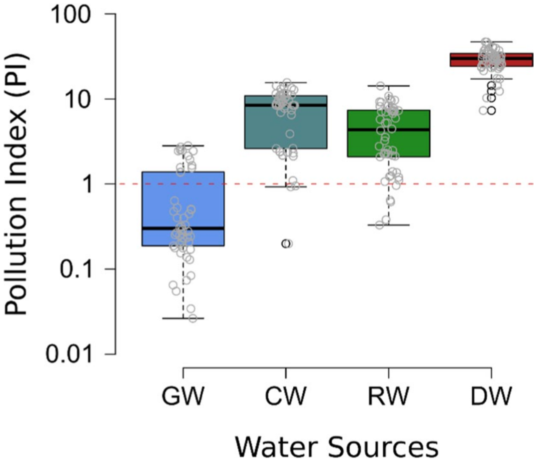

Fig. 7 Heavy metals pollution. Pollution Index values are presented for different water resources including groundwater (GW: blue), canal water (CW: cyan), river water (RW: green) and drain water (DW: red). The boundaries of the central box are the 25th and 75th percentiles; the horizontal line is the median; and the whiskers of the boxplot represent the minimum and maximum values. The Red dashed line represents the threshold limit for pollution

higher risks to aquatic organisms. For river and drains, respectively, Cu and Pb were often responsible for higher RQ_{sum}.

Pollution index

According to the pollution index, more than half of the water samples (114 out of 200) were classified as highly polluted, and the trend was as follows: Drains > Canals > River > Groundwater (Fig. 7). The pollution index for drain samples ranged from 7.3 to 46.8 (mean 29), and all the samples were categorized as highly polluted. In canals, PI values ranged from 0.2 to 15.6, with an average of 7.7. River samples showed relatively less pollution among surface water samples. The pollution index ranged from 0.33 to 14.24, with an average value of 4.83, which is twofold lower than the canal's pollution and sixfold lower than the drains. In contrast, none of the groundwater samples were highly polluted. About 28% were categorized as moderately polluted, and 72% were classified as lowly polluted based on the pollution index values (Fig. 7).

Discussion

Metal contamination and health risks

In the present study, high concentrations of heavy metals were found in most of the water samples. Approximately, 42% of the groundwater samples exceeded the permissible limits for drinking water set by the World Health Organization (WHO). Cr was detected in high concentrations and Pb was the most frequently detected heavy metal. High concentrations of Cr could be due to its extensive use in different industrial [50] and agricultural practices [51, 52], which end up in groundwater by leaching [53, 54]. Furthermore, weak and corrosive plumbing of pipes is also a source of Cr in drinking water. Consequently, these high concentrations of Cr in drinking water may cause different health issues such as respiratory problems [55], tumor formation and weak immunity [56, 57].

Among surface water samples, ~ 98% exceeded the surface water quality standards of the World Health Organization (WHO). In most of the cases, Cr and Ni were exceeding the permissible limits, and Cu concentrations were consistently high in all surface waters. The high concentrations of Cu could be attributed to its common use in the production of electronic chips, cell phones, batteries, semiconductors, the paper and pulp industry, metal processing units, and the production of insecticides and fungicides [58, 59]. Copper may enter into water bodies due to corrosion and leaching of Cu polishing, electronic plating, wood preservatives, wire drawing and printing process [60]. Ultimately, Cu might enter into human bodies via oral and dermal exposure through polluted water and cause serious gastrointestinal problems [61, 62]. A similar trend was observed in previous studies due to uncontrolled and unprocessed disposal of industrial effluents into surface water bodies [63, 64].

Ni concentrations in the river and drains fluctuated between 0–720 μg/L and 30–1789 μg/L, respectively and were higher than in previous studies [26, 63]. High concentrations of Ni might be due to industrial activities as well as erosion of mafic and ultramafic rocks [65, 66]. Although Ni is a basic constituent of dietary intake, its higher concentration may cause lung fibrosis, skin allergies, asthma and respiratory tract cancer [67]. The Pb concentrations found in the current study were similar as reported by Hussain et al. [68]. The Pb contamination could be attributed to the excessive use of agricultural insecticides, leaching and weathering of rocks and plumbing of pipes [69]. In the human body, Pb affects the gastrointestinal and respiratory systems and then enters into the circulatory system, binds to erythrocytes and distributes into soft tissues. Ultimately, it accumulates in bones, where it can persist for several years and cause lead poisoning [70, 71].

Although seasonal variation can significantly affect the contamination level, the present study focused metal contamination during dry season. Several authors have reported [34] significantly different metal contamination levals across various seasons. The variation in metal contamination might be attributed to rainfall events, temperature fluctuations and seasonal changes in industrial effluents [72, 73].

Ecological risks

In water samples collected from groundwater, canals and drains, Ni was mainly responsible for the higher toxic units. However, in the case of river water, Cu and Cr mainly contributed to the higher toxicity. The high level of Ni might be due to anthropogenic pollution in water bodies near industries [74] and mining activities. Several studies showed that an excess of Ni affects the survival of aquatic organisms by disturbing their enzymatic system [75, 76]. Several studies have reported strong negative effects of metal pollution on benthic macroinvertebrates [77–79]. Liess et al. [80] also reported the effects of Cu on predatory stream invertebrates. Furthermore, Cu is considered an inhibitor of photosystem II, leading to decreased chlorophyll content [81]. It has been reported that Cu is more toxic for algae than crustaceans [82].

Almost all the water samples collected from drains, canals and river exceeded the chronic and acute threshold limits for algae, fish and crustaceans, and indicated that these water bodies are not safe for aquatic organisms. Until now, there hasn't been any investigation focusing on the ecological risks of heavy metals available in the region to make a comparison. However, when compared to other studies conducted in Turkey [83, 84], the ecological risks in the present study are quite high.

According to the risk quotient (RQ), all metals showed high ecological risk in all water resources. Briefly, Cr was mainly responsible for potential ecological risks in 78% of canal water samples, whereas, Ni and Pb highly contaminated the drain water samples in terms of ecological pollution. The risk quotient in the present study is quite high as compared to other investigations conducted in different countries, and indicates stronger ecological effects [84–86]. Due to the exceedance of the threshold limit (> 1), the adverse ecological effects of these metals cannot be neglected.

Conclusions

Monitoring and risk assessment are crucial to protect human health and aquatic ecosystems from metal contamination. The present study represents the first comprehensive assessment in the region, considering all the water resources for metal contamination and associated human health and ecological risks together. Our results show that the water resources of Lahore are highly polluted with heavy metals, and can have serious health and ecological consequences. Therefore, urgent and comprehensive measures are imperative to mitigate the escalating risks to human health and ecosystems. Industrial effluents should be properly treated before disposal into surface water bodies. Moreover, it is highly important to make better policies and implement them to reduce environmental pollution.

Abbreviations

BRB	Bambawali-Ravi-Bedian
CDI	Chronic daily intake
Cr	Chromium
Cu	Copper
EC	Electric conductivity
GW	Groundwater
CW	Canal water
RW	River water
DW	Drain water
HQ	Hazard Quotient
HRI	Health risk index
IR	Intake rate
ET	Exposure time
EF	Exposure factor
CF	Conversion factor
BW	Body weight
MEC	Measured environmental concentration
Ni	Nickel
NIST	National Institute of Standards and Technology
Pb	Lead
PI	Pollution index
PNEC	Predicted no-effect concentration
RQ	Risk quotient
TDS	Total dissolved solids
TU	Toxic unit
WHO	World Health Organization

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12302-023-00824-2.

Additional file 1: Table S1. Detail of sampling locations with respect to water resource, site ID, sampling date and coordinates. **Table S2.** Physicochemical properties of the water samples collected from groundwater, canals, river Ravi, drains, and respective National Environmental Quality Standards. **Table S3.** Parameters used for the calculation of Chronic Daily Intake (CDI) through oral and dermal exposures are enlisted in the table. Values are presented with units and references. **Table S4.** Reference values of EC_{50}/LC_{50} (μg/L) for algae, fish and crustaceans used for the calculation of Toxic Units (TU). **Table S5.** Descriptive summary of the metal concentration (μg/L) in water bodies. **Table S6.** Hazard quotients and Health Risk Index: Oral Hazard Quotients (HQ_{oral}) and Oral Health Index (HRI_{oral}) are presented only for groundwater samples, as other water resources are not commonly used for drinking. Dermal Hazard Quotient (HQdermal) and Dermal Health Index (HRIdermal) are presented for all water samples collected from grounderwater, canals, river and drains. Data is presented in the form of minimum (Min.), maximum (Max.), average (Mean) and standard deviation. **Table S7.** Ecological risk of metal contamination based on the toxic unit (TU) is presented for three trophic levels: algae, fish and crustaceans. Toxic Units (TU) are given for each metal, and for the total toxicity of all metals detected at each site (TU_{sum}). For illustration purposes, log-transformation was performed. **Table S8.** Risk Quotients: Risk Quotients (RQ) and sum of the Risk Quotients (RQsum) are presented for all water samples collected from grounder water, canals, river and drains. Data is presented in the form of minimum (Min.), maximum (Max.), average (Mean) and standard deviation. **Figure S1.** Principal component analysis of heavy metals: Each vector in the plot represents a variable, and the direction and length of the vector indicate the contribution and correlation of each variable to the top two principal components.

Acknowledgements

The authors are grateful to Mr. Muhammad Iqbal and Mr. Muhammad Afzal from the Institute of Nuclear Medicine & Oncology (INMOL) Lahore for their support in collecting water samples. We also acknowledge the Higher Education Commission (HEC), Pakistan, for their financial support of HHI through the IRSIP fellowship (International Research Support Initiative Program).

Author contributions

HHI: conceptualization, study design, investigation, statistical analysis, interpretation of results, writing—initial draft, AS: statistical analysis, interpretation of results, writing—extension of initial draft, AQ: conceptualization, study design, supervision, writing—review and editing, SRA: supervision, funding acquisition, writing—review and editing, ML: extension of formal analysis, writing—extensive review and editing, NS: conceptualization, study design, supervision, statistical analysis, interpretation of results, visualization, writing—extension of initial draft, and review and editing.

Funding

Open Access funding enabled and organized by Projekt DEAL.

Availability of data and materials

All data generated or analyzed during this study are included in this article. However, any further details are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Received: 18 September 2023 Accepted: 10 December 2023

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