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Review Article: A Comprehensive Screening of Toxic Heavy Metals in the Water of FATA (Pakistan)

Riffat Bibi[1], Zahid Muhammad[2], Zaheer Ahmad[1], Fawad Ahmad[1,*]

[1]Department of Chemistry, University of Wah, Quaid Avenue, Wah Cantt., (47010), Punjab, Pakistan
[2]Atomic Energy Commission, Islamabad, Pakistan

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ABSTRACT

Water adulteration is one of the serious concerns in Pakistan. Among 122 nations, Pakistan is positioned at rank 80 to provide water for drinking purposes. Water reservoirs including surface and groundwater are adulterated with toxic metals throughout the country. The acceptable limit set by the World Health Organization (WHO), Pakistan Environmental Protection Agency (Pak EPA), Health risk indicators are the Chronic Daily Intake (CDI), and the Health Risk Index (HRI) is consistently contravened. The main origin of heavy metals is industrial discharge, disposal of municipal waste, and use of agrochemicals are the main sources of water adulteration. This review discusses a brief layout of toxic heavy metals in water in Federally Administered Tribal Areas (FATA) Pakistan with a special insistence on heavy metal contamination. The data assembled in this review are obtained from different research articles published in national and international journals on toxic heavy metals in the particular region. Toxic heavy metals that as copper (Cu), cadmium (Cd), chromium (Cr), lead (Pb), nickel (Ni), (Fe) Iron, and manganese (Mn) are the most significant hazardous contaminants in different regions of FATA (Pakistan). The accumulation of heavy metals in the water reservoirs causes serious health risks to all living beings. This review is on the heavy metal in the water of different areas of FATA (Pakistan) in the last few years. The levels of heavy metal adulteration in different water sources were collected from various regions of FATA agencies. The research articles of respective authors helped to determine the heavy metal concentration mentioned in the standard literature. The determined concentration of some heavy metals was found safe mentioned by organizations that as the WHO, USEPA, EUC, and EPA. This review article aims to study the concentration of heavy metals in water sources of FATA (Pakistan).

Riffat Bibi: She is graduated from University of Wah, Wah Cantt, Pakistan. Currently she is pursuing PhD. in chemistry from the same university. Her research interest is in synthesis of novel materials and biomaterials and its applications in water purification.

***Corresponding Author: Fawad Ahmad** (*fawad.ahmad@uow.edu.pk*)

Zahid Muhammad: He completed his B-tech Degree in Chemical Engineering from Sarhad University. Currently he is working in Atomic energy commission in Pakistan. His research interest is in water purification and synthesis of such material having the potential for decontamination of water.

Zaheer Ahmad: He received his PhD. Degree in organic chemistry from University of Karachi in 2009. From 2010-2021 he worked as an assistant professor in University of Wah, Department of Chemistry. Since 2021 till present, he is working as an associate professor in University of Wah, Department of Chemistry. His work is focused on Medicinal Chemistry and Natural Products.

Fawad Ahmad: He received his PhD. Degree in Physical Chemistry in 2018 from University of Science and Technology of China (USTC) under the supervision of Professor Jie Zeng Group at Hefei National Laboratory for Physical Sciences at Microscale USTC. He moved back to his homeland and join University of Wah, Wah-Cantt, Pakistan as an assistant professor of chemistry in August 2019. His work is focused on synthesis of nanomaterials and its catalytic application for fuel cell and water decontamination.

Content

1. Introduction

Water is vital for all life. The existence of life without water is not possible, 70-80% of the human body contains water, and the percentage of water in cell, blood, and bones are 90%, 75%, and 22%, respectively. The studies revealed our earth covered an area of 51 crore kilometer square, in which 36.1 crore kilometer square is the area covered by seawater. Water reservoirs are found in the form of seas, rivers, lakes, streams, canals, and dams. The physicochemical parameters that ensure the quality of water are pH, TDS (Total Dissolve Solid), TSS (Total Suspended Solid), DO (Dissolved Oxygen), BOD (Biological Oxygen Demand), COD (Chemical Oxygen Demand), total nitrates and phosphorous, and trace elements. Different agencies (the WHO, CPCB, ICMR, APHA, and ISI) set acceptable and safe limits for all parameters that ensure the water quality [1].

All countries need to achieve SDGs (Achieve sustainable development goals) given in the 2030 Agenda. This agenda includes the protection of water sources used for different purposes. Quality of water is considered to be necessary for achieving the SDGs goals and is also related to the socio-economic progress of the country. Good quality water ensures the healthy life of the population. The issues regarding water quality under discussion are minimizing water pollution, reducing toxic things contamination, introducing recycling, and removing toxic contaminants [2].

Among all the toxic pollutants, heavy metals have a special matter of concern in water adulteration. HMs are those metals having greater mass or high density than water. These HMs are categorized as essential and nonessential metals, the essential heavy metals include Zn, Fe, etc. and the non-essential metals are As, Pb, Cd, Co, Ni, Hg, and Cr [3].

They all are capable to induce toxicity in living systems and cause ecological pollution. The vulnerability to these HMs is increasing day by day due to the use of agrochemicals, industrial waste, domestic disposals, and the leaching process of metals from soil to water bodies. Due to the overpopulation, urbanization and industrialization increased to fulfill the needs. In this case, the number of toxic chemicals in the surface and groundwater increased by the standard inducing lethal diseases. The natural point sources for this contamination are climate change, soil erosion, volcanic eruption, and weathering process of rocks. Some reasons for this toxic adulteration is biogenic activities [4].

Heavy metals are found deep in the earth's crust, but the degradation of some biogenic material allows the HMs to increase their amount on the earth's surface [5]. Many harmful chemicals are deposited in soil sediments of water bodies anions also play a vital role in water. The concentration level of some metals in the soil of some selected district of Khyber Pakhtunkhwa is as follow: Mn> Zn > Cr > Ni > Cu [6]. Heavy metals even in a minute amount deposited in freshwater due to leach from soil and rocks weathering [7].

1.1. Health risk index

The health risk index (HRI) is used to determine the adverse or acute effect of metals in adulterated sources such as water, soil, and food crops. For example, the use of food crops was estimated using the formula [8]:

$$HRI= {}^{DIM}/_{RfD}$$

Where,

HRI: Health Risk Index,
DIM: Daily intake of Metal, and
RfD: Reference Dose of Metal.

1.2. Hazard index (HI) for HMs

North and central Punjab, Southern Sindh, and central Khyber Pakhtunkhwa reported more dangerous regions in terms of HMS. To determine the potential non-carcinogenic impact of the vulnerability of HMs in water, the HI was calculated for each metal by EPA (Environmental Protection Agency), as follow:

$$HI = \Sigma\ HQ\ nk =1 =HQPb + HQCr + HQCd + HQCu + HQNi$$

This value of HI compares with standard values if HI>1 means the non-carcinogenic impact of HMs. If HI<1, it means the carcinogenic or harmful impact of HMs [9]. Groundwater is the decisive mean of drinking water; one-third of human needs depend on this, but numerous activities make this not fit for human use [10]. Globally 780 million population have no good quality water for drinking. 3.4 million died due to water-related lethal diseases, and 2.5 million have no proper sanitation system [11]. Near the coastal area, marine sediments are considered as a large contributor to HMs. If the balance between the sediment and marine water is disturbed the transfer of metal to water and its level increase in water and affects the aquatic ecosystem [12]. The human vulnerability to 35 heavy metals among these 23 is harmful and toxic. As metal cations, they showed a tendency to sulfur and inhibit the functioning of enzymes, and also enhance the chances of cancer, with long-term influence on genetics [13]. Pakistan has four provinces; the water quality status of Khyber Pakhtunkhwa (2002-2006) was reported in **Table 1** the safe and unsafe limits [14, 17].

The groundwater samples of Khyber Pakhtunkhwa and Sindh comparatively have a high level of Cd adulteration, it can cause chronic health problems like reproduction issues damage bones and cause cancer [15-17]. It is reported that mostly inorganic (metals) form complexes with organic molecules and in such a way, the toxicity level can minimize. In

Table 1. Water quality status of Khyber Pakhtunkhwa (Pakistan) in 2002 to 2006 [17]

S. No.	Years	Total Sample Taken	Safe		Unsafe	
			No. of Samples	%	No. of Samples	%
1	2002	35	8	23	27	77
2	2003	24	12	34	22	65
3	2004	35	5	14	30	86
4	2005	46	8	17	38	83
5	2006	46	11	24	35	76

water bodies, many factors contribute to regulating toxicity such as pH, water hardness, etc. [18]. Some metals showed high affinity towards organic matter such as Zn, Cd, and Pb. The amount of organic matter critically affects the metal binding with the sediments minimizing the adsorption of Cd and Co but enhancing the adsorption of Zinc [19]. The HMs are the most toxic inorganic, persistent, and bio-accumulative toxicants [20]. Nowadays, metals are common toxicants that are not biodegradable to fewer toxic forms. Surface water runoff also adulterates the groundwater is a big matter of concern [21, 22]. Among metals Fe, Cu, and Zn are vital micronutrients in a biological system [23]. Some metals are vital for living systems and perform different functions such metals are Ca, Na, K, Cu, and Zn, but the excess amount of these metals above standard limits is toxic and harmful. Toxic adulterations not only destroy water quality, but can pose lethal effects on living beings [24]. Different parameters were used to determine the coastal sites of Pakistan such as adulteration factor, Pollution load index, Mean effect range medium, enrichment, and geological accumulation factor [25].

1.3. Legislation in Pakistan environment

In 1975, government of Pakistan inveterate ordered the Ministry of Environment in the 2010 constitution 18th amendment to inveterate the environment and ecology. The first time Pakistan introduced ecological legislation PEPO (Pakistan Environmental Protection Ordinance) aims of this institution to follow the policy set by EPC (Environmental Protection Council). After that, PEPO was replaced with PEPA (Pakistan Environmental Protection Agency). In 1992, the government accepted the national conservation strategy and worked on issues regarding the environment faced by Pakistan at that time. Their recommendations have 14 points in this regard are protecting water reservoirs, sustaining, and protecting fish farming, proper handling of Urban waste pollutants, etc. The NCS focused on the severe conditions that take place in the environment. Then, NEQS (National Environmental Quality Standards) set the prescribed limit for the toxic discharge that comes from industries, but our government hesitates to implement such legislation due to a lack of enough resources. In the 1990s, programs were made to aware the private sector about the protection of the environment, in this regard; APTPMA (All Pakistan Textile Processing Mills Association), OICCI (Overseas Investors Chambers of Commerce and Industry), OCAC (Oil Company Advisory Committee), and FPCCI (Federation of Pakistan Chamber of Commerce) worked together for the betterment of environmental protection. To control the organized pollution program that is SMART (Self-Monitoring and Reporting Tool) launched, shares data on a regular basis with EPA [26].

2. Water Sources

Water sources are illustrated in the **Figure 1**.

2.1. Ground water source

Earth's 0.06% of water exists in the form of groundwater. It is found in the form of aquifers. The aquifers are the geologic unit that is permeable to supply water to the wells [27]. About 50 % of potable water is groundwater around the globe. Different groundwater

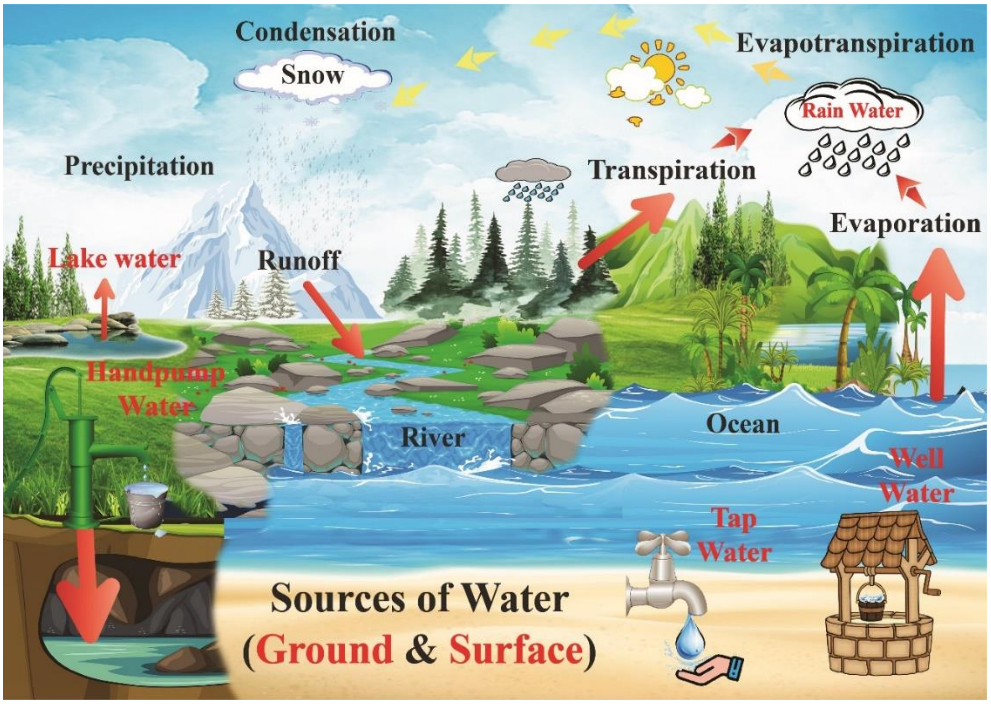


Figure 1. Water sources

sources are wells, boreholes, and springs water. Groundwater as borehole water is commonly found in urban areas. Similarly, from the ground wells water is gathered during raining season [28]. Generally, it is considered free from any adulteration, but its quality decline with the passage of time due to increases the anthropogenic and natural contributions. However, it is considered comparatively cleaner than surface water because of the natural purification system of the soil [29]. Groundwater adulteration is due to industrial effluent, soil erosion, and leaching processes. The degree of adulteration depends on the volume of the affected area, toxicity concentration, solubility, and intensity of the adulteration, rainfall, depth of water table, filtration, rocks, and soil texture [30]. In Pakistan, the borehole is further a source of drinking water. If it is adulterated with toxic metals can affect human health. The problem related to water quality ruination is not limited to surface water, the groundwater situation also has serious concerns. Groundwater resources near wastewater adulterated with toxic pollutants and not have adverse effects on all living beings [31]. It is a serious concern for the area where groundwater is used for drinking. To compute the risk assessment of arsenic (As) adulteration found five times greater in the groundwater of Pakistan (Indus) than standard making the water carcinogenic for humans [32]. Although some areas in the country are safe, the study indicates about 50 to 60 million people using groundwater for drinking might be at risk [26].

2.2. Potable water sources

Water is the main constituent of all living beings. Billion people do not have clean water due to toxic adulteration. About 6% of deaths all around the world are associated with lethal water-borne diseases. It is necessary to find ways to improve the water quality because good quality water improves the life of human beings and also economic productivity. Besides, many people in the third world and developed countries need clean water for drinking. Therefore, portable water purifiers are the source to clean water for drinking purposes [33]. Various water sources such as ponds, streams, rivers (surface water), borehole, and shallow wells (groundwater) need to be monitored fresh water is recommended because it fulfills the criteria set by the WHO for human consumption. However, 75 % of fresh water is in the form of glaciers, 24 % is in groundwater, and 1 % is found in lakes, rivers, and soil [34]. Fresh water sources are also used for domestic, industrial, and agricultural purposes. These sources are mainly lakes, streams, rivers, wells, taps, boreholes, etc. [35].

2.3. Surface water sources

Water sources such as rivers, streams, and lakes are commonly termed surface water sources. Surface water is used as a potable water source where groundwater is not sufficient for different purposes. Many people have migrated to urban areas for the betterment of life, but due to urbanization, water quality is a major concern [36]. In rural areas where groundwater is not sufficient source, rainwater is the alternate form of natural and pure water. However, this water contains carbonic acid due to the dissolution of atmospheric carbon dioxide in rainwater. Rainwater is also used for domestic, agricultural, and environmental purposes [35].

2.4. Packaged water sources

Usually, packaged water is supplied in the form of a bottled because it is affordable and easily available. Thus, most people consume sachet water [37]. Bottled water is also available, however, consumed by a relatively lesser percentage in Pakistan. Water packaging has become a profitable venture. Some manufacturing industries are responsible for water adulteration when it is located near groundwater [35].

3. Sources of Water Contamination

Water is very vital to sustain life on the earth and about 2.5% of surface water is used to fulfill our needs. Water quality is a major concern all around the world. The investigation of water quality showed that different sources are responsible for water adulteration which is organic and inorganic pollutants. Types of water contamination sources are shown in the **Figure 2**.

3.1. Point sources

The point sources of adulteration are those which directly discharge the waste in water bodies such as industrial, domestic, and municipal waste effluent. In developing countries, point sources are responsible for water pollution.

3.1.1. Vehicular emissions

Emissions from different automobiles are the point source of pollution especially, atmospheric pollution. In Pakistan, due to limited resources, it is difficult to measure each contribution in different regions. In Urban areas, the limit of toxic contaminants is more than the standards (WHO, USEPA). Heavy

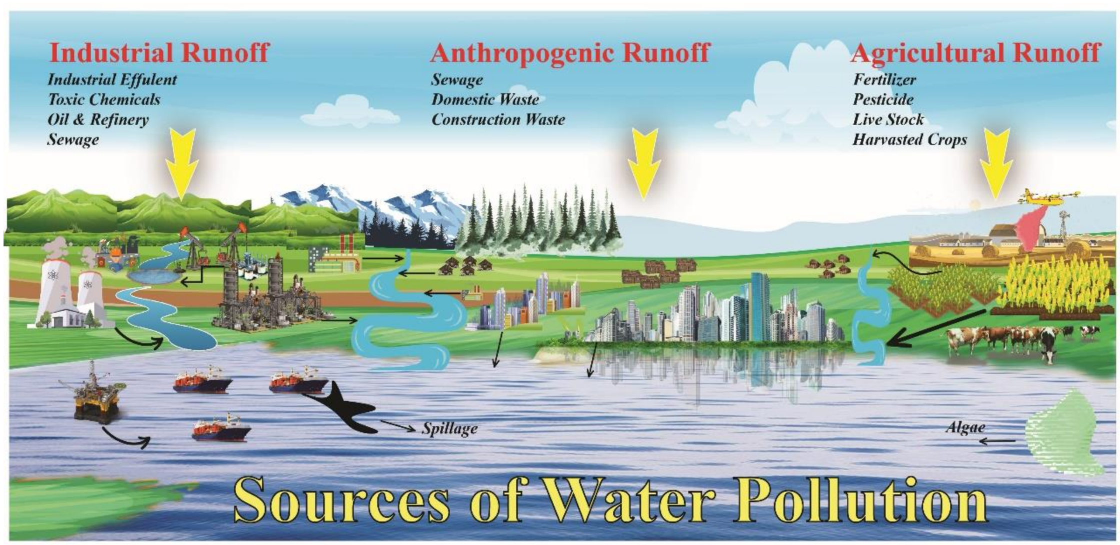


Figure 2. Sources of water contaminations

transport constitutes high smoke which contaminates the air and soil at the roadside mostly Zn, Cu, Ni, and Pb observed. In Pakistan, the smoke released from automobiles is a rich source of Pb contamination [41].

3.1.2. Domestic and municipal effluents

In developing countries, limited resources are available to dispose of domestic waste properly. In 1990, the world produced 1.3 billion municipal and domestic wastes. In Pakistan, municipal and domestic waste directly dump in fields, water bodies, and drainage systems [44]. There is a lack of a proper disposal system for such waste. Pakistan is capable of treating just 8% of the waste from an urban site. At the primary level, plants are working for the treatment of municipal waste, but they ate not enough to meet our country's requirements. Improper dumping of waste domestic waste contaminates natural resources such as water and soil and adversely affects the life of all living beings. A survey of a different region of Pakistan reported poor sanitary conditions [45]. Municipal effluent is one of the reasons for toxic metal adulteration. In the swat, valley soil is contaminated with cadmium due to poorly disposed of Cd-batteries. These metals from soil runoff through rainwater to water bodies and get contaminated ad effect aquatic and human life [46].

3.1.3. Industrial sources

With the rapid increase in population and urbanization, environmental degradation occurs. The emission from different industries such as chemical, metallurgical, microelectronics, oil mills, pesticide, paint, dyes, and fertilizer industries, etc. contributes to metal adulteration in water resources. The effluent coming from industries in water led to a decline in the quality of potable water [47, 35]. Various methods such as the combustion of fuel, burning of coal, and nuclear reactions are responsible for the deposition of toxic metals such as Se, B, Cd, Cu, and Ni in the environment. The UNIDO (United Nations Industrial Development Organization) in 2000 reported that the textile, metallurgical industry, metal refining, and paper pulp are the main contributor of toxic metals in Pakistan. Above mentioned industries induce metals and metalloids such as Ni, As, Fe, Pb, Hg, Cr, Cd, Cu, and Co. In Pakistan among 388 cities, only 8 have the resources to treat wastewater properly [48]. The two industrial estates of Pakistan, that is SITE (Sindh Industrial Trading Estate) and KITE (Korangi Industrial and Trading Estate) in Karachi do not have proper waste effluent treatment plants. In Khyber Pakhtunkhwa, the Kabul River contains highly polluted discharge annually. The main drains of wastewater in Peshawar contain higher limits of Pb and Cr than the prescribed limits [49]. Industrial contamination in water increases day by and the concerned authorities do not show interest to overcome this by installing proper plants for treatment. The industries including textile in Faisalabad, Leather tanneries in Sialkot and Multan, electrical goods in Gujranwala surgical objects in Sialkot are responsible for metal adulteration. River Kabul (Khyber Pakhtunkhwa) every day collects the amount of 80,000 m^3 of industrial effluents [41]. It is concluded that the use of industrial wastewater and sewage for irrigation purposes induces toxic metals in fruits and vegetables, and then through the food chain become part of the human body and causes lethal diseases [50].

3.1.4. Natural sources

The main reason for water adulteration is both natural and human-induced activities. Soil and groundwater are the natural sources of water adulteration by toxic metals. Geologically the extent of toxicity depends upon the nature and number of rocks present and climate conditions. Most of the heavy metals present in soil and groundwater are, Mn, Sn, Co, Ni, Cu, Cd, Hg, Pb, Zn, and Cr which increases the level of toxicity in the environment [51]. Forest fire, aerosols, fossil fuels, and emissions from natural vegetation are the natural sources of metals in the ecosystem [52]. In Pakistan, various natural phenomena are responsible for the deposition of toxic metals such as mining, sedimentation, erosion of soil, and weathering of rocks [41].

3.1.5. Urbanization in Pakistan

In urban pollution, domestic waste contributes as a primary pollutant source in the environment. The waste from households collects in pipelines that drain it directly into streams and rivers without any appropriate treatment. In Pakistan, the river Ravi continuously deposited toxic effluent without any treatment [54]. The production of waste per day in Karachi is 435 MGD -(million per day), and the capacity, of the plant to treat it, is 151 MGD, but in actual practice, only 54 MGD is treated. In Harnoi, stream (Abbottabad) is badly affected because 87% of waste is deposited directly and causes water adulteration [53]. The proof of this adulteration is the growth of algae and the accumulation of organic matter that makes water dangerous for aquatic life [26].

3.2. Nonpoint sources

The nonpoint sources are considered as where no point source exists, but due to surface water runoff, the water bodies become contaminated such as the irrigation process [38]. In Pakistan, 1228 out of 6634 industries are considered to be responsible for water adulteration because their waste effluent contains toxic organic and inorganic material. The industries working in Pakistan include food, fertilizer, pharmaceutical, textile, steel, ceramics, petrochemicals, and leather tanneries. The outflow from different industries induces toxic pollutants such as Mg^{2+}, Ca^{2+} Cl^{-}, $CO_3{}^{2-}$, $HCO_3{}^{-}$ Ag^{+}, Na^{+}, K^{+}, and toxic heavy metals like arsenic (As), lead (Pb), mercury (Hg), chromium (Cr), iron (Fe), cadmium (Cd), nickel (Ni), copper (Cu), zinc (Zn), cobalt (Co), and manganese (Mn) [39]. Water adulteration with toxic materials results in the pollution of water by changing the water quality parameters such as COD (chemical oxygen demand, and BOD (biological oxygen demand). TSS (Total suspended solid) and TDS (Total dissolved solid) that water is not used for domestic purposes [8]. There are various point and nonpoint sources for water adulteration. Some sources are natural (erosion and weathering) and some others are anthropogenic. The most concerning and toxic contaminants are heavy metals. Polluted surfaces and groundwater have changed in color and taste. Its chemical and physical properties are changed [40].

3.2.1. Agricultural sources

Pakistan being an agricultural country excessively used agrochemicals for better yields of crops. In South Asia, Pakistan is the second largest country in the use of agrochemicals and their consumption increases with the passage of time. The use of different organic and inorganic agrochemicals includes liming, pesticides, sewage sludge, and fertilizers. All agrochemicals are responsible for heavy metal adulteration in water and soil. Animal manure also induces Cu, Zn, Co, and Mn. Swage contaminates the soil with Zn, Cr, Pb, Cu, and Ni. These heavy metals leached with rainwater into water bodies and cause water adulteration. The by-product of some fertilizers is heavy metals. The production increased from one million to three million from 1981 to 2003. In Rahim Yar Khan, the excessive use of agrochemicals increases heavy metal adulteration, in Swat due to the extensive use of fungicides contaminating the soil with heavy metals [41]. The impact of the use of agrochemicals on soil and water bodies is adverse. From soils, these chemicals through soil erosion or leach from soil to water bodies this runoff contains phosphates. Nitrogenous compounds and various toxic metals from pesticides adulterate the water resources both surface and groundwater. For aquifers, nitrates are the most common contaminant [42, 43]. In 1954, farmers started to use pesticides to kill pests. Now, its use increased day by day used all over Pakistan in four provinces for cotton crops 70 to 85% of pesticides are used and the remaining 4% are used for rice, maize, sugarcane, vegetables, and fruits. Approximately, 500,000 people in Pakistan are affected annually by the use of agrochemicals and ten thousand among them die [26].

4. Toxic Heavy Metals

4.1. Chromium (Cr)

The role of chromium in carbohydrate metabolism is important, but the compounds are toxic. Cr in a +6-oxidation state is carcinogenic. The previous work showed that 75% of water samples from Khyber Pakhtunkhwa, and 25% of water samples in Sindh had high concentrations of chromium [17]. The obtained HQ values showed its risk in 40% of samples of ground and surface water. The HQs of Chromium was (12.05-19.36) the highest value for the groundwater of Kasur city and surface water of river Kabul (Peshawar) [55]. Chromite is the source of Cr used in the preparation of stainless steel, some chromium salts are widely used in industrial and refractory materials [56]. The health hazards caused by chromium are skin irritation, cancers, digestive, excretory, respiratory, allergic dermatitis, and reproductive diseases. The studies showed that workers in leather turneries had chromium exposure their health is at risk [57]. The results obtained from workers of Sialkot (Pakistan) had 13% skin rashes, 12% chronic bronchitis, and 8% gastritis, and 54% of workers' blood samples had chromium above the upper limit given by the Agency for Toxic Substance and Drug Registry [58,41].

4.2. Nickel (Ni)

In mineral resources of Pakistan, nickel deposits are found in different regions of Pakistan such as Malam Jabba, swat contains 0.4-0.8% nickel, and Teru and Pakora had up to 0.85% nickel reported in ultramafic rocks [56]. A high concentration of nickel was reported in groundwater samples of Khyber Pakhtunkhwa e.g., 0.002 to 3.66 mg/L. Nickel in higher limits can cause serious health risks such as lung fibrosis, kidney, cardiovascular, cancer, and respiratory diseases. The reported work on nickel hazards showed approximately 36% of water and soil samples pose risk, and the water samples of Gadoon (Khyber Pakhtunkhwa) [17, 59]. Nickel adulteration also reported in blood samples from different regions of Pakistan confirmed the Nickel accumulation. A positive correlation between Ni level in scalp hairs and cancer in females of Pakistan was found [41, 60].

4.3. Lead (Pb)

Pb is used in ammunition, the manufacture of lead storage batteries, in petroleum as an octane enhancer and gasoline antilock, in the construction industry, give corrosion protection, in the glass industry, and glaze of ceramics [56]. The standard limit given by the WHO for Pb is 0.01 mg/L. The reported work on the ground and surface water samples taken from different regions of Pakistan showed the amount of Pb is 0.001-0.38 mg/L. The water samples of Khyber Pakhtunkhwa and Karachi reveal high concentrations of Pb in drinking water [17, 61]. The toxicity level of Pb obtained HQ value of samples of water, air, and soil showed that Pb had no risk through soil contamination. However, it induced bout 38-50% risk through samples of groundwater and surface water samples in Pakistan. The high HQ value of Pb was found for the groundwater and surface water samples of Gadoon Amazai, Bara-river, and Swat from Khyber Pakhtunkhwa and different regions of Karachi [17]. The useful functions of Pb in the human body are not known however, it is toxic in high concentration. Therefore, exposure to high concertation cause health problems and damages the nervous, digestive system, renal, and hepatic functions, cardiovascular, reproductive system, immune system, and kidney functions [62]. Pb can cause life-threatening conditions even in minute concentration during pregnancy such as delaying the birth process, the birth of a low-weight baby even leading to miscarriage [63]. In Pakistan, human samples of blood, hair, and nails were found high levels of Pb adulteration. It was observed that the people who live near the manufacturing industries of batteries and automobiles have a high concentration of Pb in their blood samples. Lead is a toxic poison for the human body, it accumulates in the body and is capable of causing lethal diseases [64-66, 41]. At lead-related workplaces, the worker's exposure to Pb is high, especially in Rawalpindi city; the workers are seriously affected by hepatic, renal, hypertension, and hematological problems.

4.4. Arsenic (As)

The risk level of arsenic adulteration in water is still neglected by the (PCRWR) Pakistan Council of Research in water resources [17, 67]. To estimate the arsenide deposits of samples obtained from the Gilgit belt in Khyber Pakhtunkhwa and near Hunza, Atomic Emission spectroscopy was used. Arsenide is the mineral source of arsenic [56]. The long-term vulnerability to high concentrations of arsenic can cause serious risks to the health of all living beings. The diseases caused by arsenic such as damage to the blood cells as well as blood vessels, hyperkeratosis, cardiovascular diseases, pain and needles sensation in hands and feet, and cancer [68]. It was reported that 17-22% of people of Sheikhupura (Pakistan) had liver, and respiratory problems, skin infections, diabetes, and blood pressure due to the accumulation of Cd and Arsenic in their blood and hair samples, especially in cancer patients [69-71]. About 1.5 million people in all around the world and 70% of people in the different studied regions are adversely affected due to arsenic vulnerability through water sources. The HQ value of arsenic exceeds the threshold for water. The high adulteration of arsenic in ground and surface water of different region of Pakistan have been studied these areas are Chashma, Terbela water reservoir, and the water of wells in Multan. The groundwater in the vicinity of the Indus River has high level of arsenic adulteration. Based on a survey, 13.5 % of people of Khairpur district had skin inflammation due to arsenic [17, 41]. Arsenic adulteration in drinking wastewater gives rise to a threat to human health and life. Arsenic is a highly toxic, persistent, and bio-accumulative heavy metal [72]. Due to poor drainage systems of domestic wastes and chemicals, corrosion of underground water pipelines poses arsenic adulteration. To overcome the risk of arsenic adulteration proper guidelines regarding drinking water safety and purification should be implemented [73]. Internationally the standard limit of arsenic given by the WHO is 10 μg/L and 50 μg/L for Pakistan but its level exceeds 1100 μg/L, comparatively [74]. If the number of programs regarding arsenic mitigation helped to learn about arsenic adulteration at various levels (**Figure 3**) [75].

4.5. Arsenic (As)

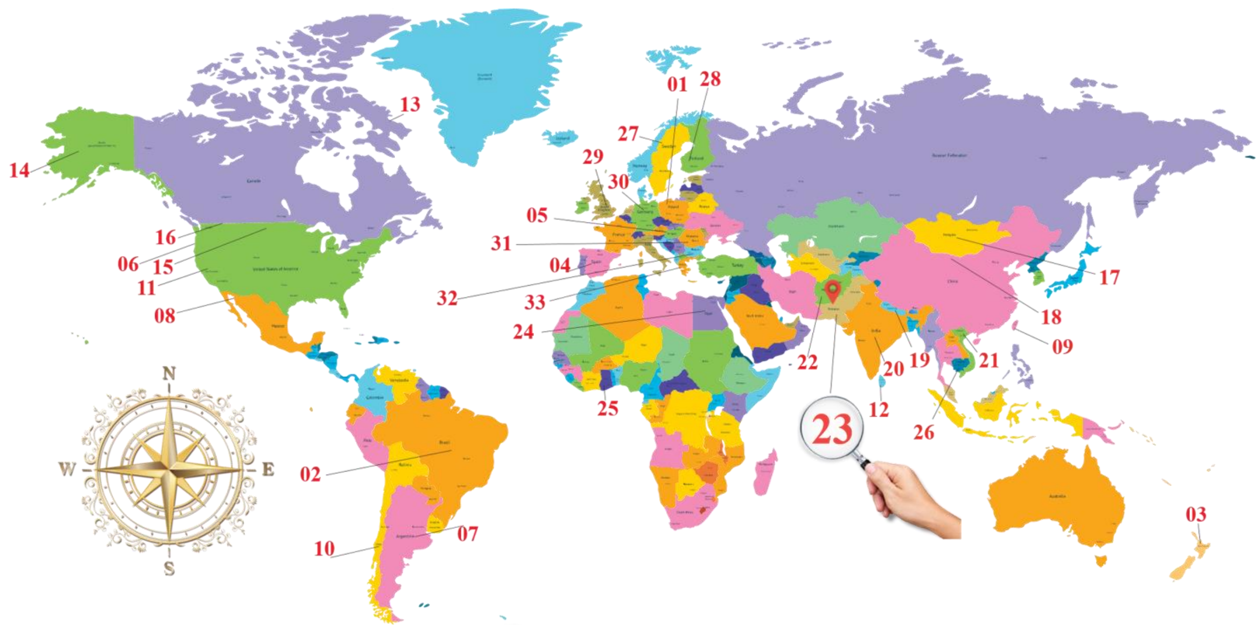
The optimum limit of Zn is beneficial for all living beings, but the vulnerability to the greater amount of Zn becomes perilous. Zinc can accumulate through ingestion and inhalation can increase the symptoms of cough, fatigue, fever, and nausea. However, the oral uptake poses abdominal pain and vomiting. In Pakistan, the risk assessment of Zinc is minute and limited to some regions. The HQ value reported in the Gutter Baghicha site (Karachi) was 1.79. However, there is no more human sample that indicates a higher concentration of Zn in Pakistan [41]. As far as its harmful effect in high limit on the basis of its low melting point and its electrochemical activity as an anode it is used in the manufacturing of brass (an alloy of Copper and Zinc), galvanization, rubber vulcanization, inks, dyes and photocopying, industrial plants construction, and in paints. In nature, it is found in the form of oxides, sulfates, and carbonates [76, 77].

4.6. Iron (Fe)

Iron is the third most abundant element on Earth’s crust. Pakistan has one billion tons of iron reserves from which 30000 tons/year of iron is exploited through commercial mining. Iron is extracted for the manufacturing of steel alloy. It has mostly existed in metamorphic, igneous, and sedimentary rock. The blood samples collected from the people of Karachi, Peshawar, and lower Dir, were showed a high level of iron [41, 56]. The exceeded level then standard can be hazardous and induce diseases like heart disease, liver disorder, diabetes, and cancer [78]. Although iron is essential for many reasons, but its exceeded amount can Parkinson’s and Alzheimer’s diseases [79].

4.7. Manganese (Mn)

Manganese is a vital trace element, but long-term vulnerability cause health hazards such as



1.	Poland	12.	Sri Lanka	23.	Pakistan
2.	Brazil	13.	Nova Scotia, Canada	24.	Egypt
3.	New Zealand	14.	Fairbanks, Alaska	25.	Ghana
4.	Spain	15.	Millard Country, USA	26.	Cambodia
5.	Hungary	16.	Fallon, Nevada, USA	27.	Sweden
6.	Lane Country, USA	17.	Inner Mongolia, China	28.	Finland
7.	Argentina	18.	Xinjiang Uighur, China	29.	United Kingdom
8.	North Mexico	19.	Bangladesh	30.	Germany
9.	Taiwan	20.	India	31.	Romania
10.	Chile	21.	Viet Nam	32.	Bulgaria
11.	Lassen Country, USA	22.	Afghanistan	33.	Greece

Figure 3. Country affected by arsenic contamination Pakistan ranked 23rd worldwide

neurological disorders that damage the nervous system, interfere with the absorption of iron from the diet and lead to the deficiency of iron causing anemia [80]. Manganese, cadmium, and lead together can disturb the function of neurotransmitters, the hematopoietic system, and induce oxidative stress. Mn is a necessary trace element, but overexposure can cause health issues like nervous system disturbance and permanent neurological disorders [81]. The results obtained from the studied region showed that the HQ value for manganese in the air is greater than the threshold limit, especially in Rawalpindi and Karachi. The reported work on the human blood samples obtained from the Peshawar and Lower Dir had high concentration of Mn [41].

4.8. Copper (Cu)

Copper is vital at moderate limits, but greater vulnerability to the high limit than standard can induce serious risks to health such as chill sensation due to cold, headache, eye irritation, fatigue, etc. Consistent exposure cause discoloration of both hair and skin [82]. The toxic effect of Cu was not reported through other media except water. About 4% of hazards through water are due to water adulteration with copper. The water samples taken from Lahore give an HQ value of 4.29. Copper was also found in the blood samples of people resident of different regions of Pakistan [41].

4.9. Cadmium (Cd)

Cd is one of the toxic heavy metals that is responsible for environmental pollution. The accumulation of cadmium is due to various activities of human beings. These activities include the use of Cd in different industries for different purposes such as NICAD batteries, as color pigments, as PVC polymer stabilizer, refining and smelting of Cu and Ni, combustion processes, Volcanic eruption, in non-ferrous metal smelters, rocks erosion, mining of different metals, and forest fire [62,83]. There are two main ways for the absorption of Cd in the human body that are gastrointestinal tract and respiratory tract. However, minute absorption takes place through the skin. First Cd enters the body and is transported via the bloodstream then absorbed in the kidney, gut, and liver. The excretion of Cd takes place through milk (during lactation), saliva, and urine. Long-term vulnerability towards Cd high limit can induce harmful impacts on human health such as testicular damage, Osteomalacia, damage hemopoietic system, kidney, and reproductive issues, vomiting, diarrhea, muscle cramp, sensory problem, liver injury, lungs damage, induce contract eye disease, and cancer. The Contamination of aluminum and cadmium was reported to damage kidneys in Pakistan [84-86]. Cadmium adulteration has been a concerned issue all around the world. In Pakistan, their concentration is different in different regions. The water samples obtained from different regions showed a higher HQ value for cadmium. The surface water of Akberpura and Nowshera (Khyber Pakhtunkhwa) was risky in Cd adulteration. However, Peshawar had an HQ value for an air of about 90.8. Approximately 72% data of HQ value showed beyond the threshold limit of 1 [41, 87]. The prescribed limit by the WHO for some heavy metals is presented in **Table 2**.

Table 2. The WHO standards for heavy metals

Heavy Metals	Symbol	Prescribed Limit (mg/L)
Arsenic	As	0.05
Cadmium	Cd	0.005
Chromium	Cr	0.05
Copper	Cu	0.05
Iron	Fe	0.3
Lead	Pb	0.05
Manganese	Mn	0.1
Mercury	Hg	0.001
Nickel	Ni	0.02
Zinc	Zn	5.0

5. Study Areas

The Federally Administered Tribal Areas (FATA) was a tribal region in northwest Pakistan (**Figure 4**). In the north and the west, it shares Afghanistan, in the east Khyber Pakhtunkhwa, and in the south Baluchistan.

The FATA region consists of seven different agencies named Bajaur, Mohmand, Khyber, Orakzai, Kurram, North Waziristan, and South Waziristan. Geographically, the six Frontier Regions from north to south are named FR-Peshawar, FR-Kohat, FR-Banu, FR-Lakki Marwat, FR-Tank, and FR-Dera Ismail Khan. In 2018, it is merged with the province of Khyber Pakhtunkhwa. The Baluchistan, FATA, and Khyber Pakhtunkhwa are rich in mineral resources among the three Khyber Pakhtunkhwa and FATA have many metallogenic domains [56].

5.1. Bajaur agency

This agency covered an area of 1290 km^2 and has a 1.1 million population. It connected with Dir lower (Hindukush ranges) in the north, the Malakand region (river Panjkora) in the east, in the south Mohmand agency, and the Kunar valley (Afghanistan) in the west (**Figure 5**). The climate of this area is arid, and semi-arid, with extreme summer and winter, and average annual rainfall is ~ 800 mm. The topography of area has mountainous, hilly, and plain areas, and geologically different types of rocks Mesozoic intrusive, metamorphic, Permian, Triassic, Paleozoic, lower Paleozoic rock sand, and undivided Precambrian rocks [88].

Approximately 60% of the total area in the east and west consists of mountains. In this area, the main sources of drinking water are springs, which mainly discharge to the surface in the pores of the rocks. Due to a lack of resources, people of this region used poor-quality water for drinking purposes. 40% of the area is

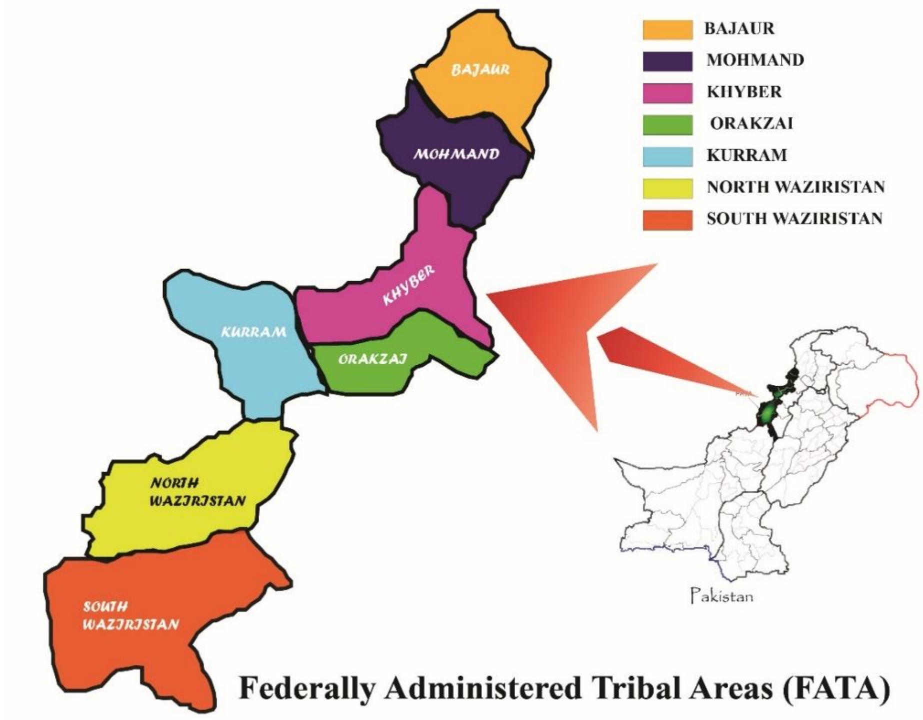


Figure 4. Map of region FATA

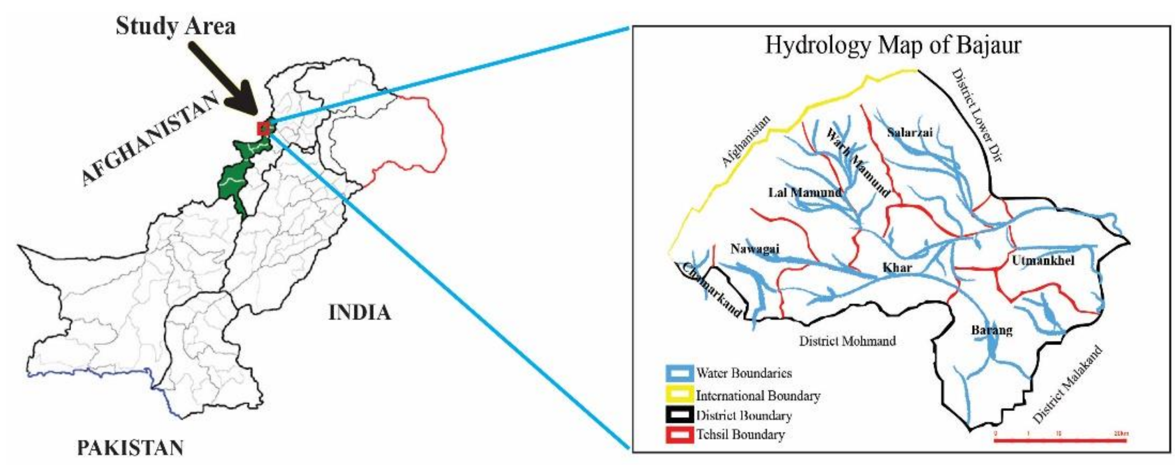
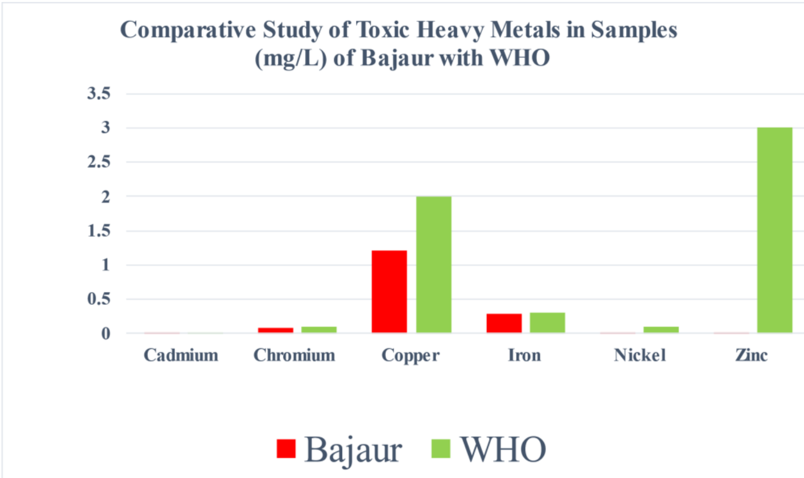


Figure 5. Hydrology map of Bajaur agency [89]

mainly composed of carbonate sediments and volcanic rocks. Groundwater in wells and deep aquifers are of the best quality and used for drinking. The water samples collected from this region of FATA (Pakistan) showed that the water quality of tube wells is better than the water from springs and hand pumps. Springs water showed high noncarcinogenic risks (HRI) related to the PTEs level. However, tube wells showed safe limits. Both geogenic and human activities contribute in water adulteration in the study area. Based on the results, the water from deep aquifers in tube wells is safe and should be used for drinking [89]. The concentrations of heavy metals in Panjkora River water were in the order Zn>Cu ≈ Pb>Ni ≈ Cd with concentrations of 0.30, 0.01, 0.01, 0.0, and 0.0 mg/l, respectively [90]. In Dargai, the concentrations of heavy metals in industrial effluent samples were analyzed. In the steel mill



Metals	mg/L	
	Bajaur	WHO
Cd	0.0019	0.003
Cr	0.09	0.1
Cu	1.207	2
Fe	0.29	0.3
Ni	0.017	0.1
Zn	0.018	3

Figure 6. Comparative study of HMs limit with the WHO (Bajaur)

effluent samples, the concentration of heavy metals was in the order of Fe > Zn > Cr [91]. The water samples of Tahsil Salarzai (Bajaur agency) showed that the toxic heavy metals adulteration in water according to the acceptable limit given by the WHO were in order Cu>Fe>Cr>Zn>Ni>Cd (**Figure 6**) [100].

5.2. Khyber agency

Khyber agency is located in the north of FATA (Pakistan). Its border me ets with Afghanistan, Peshawar, Kurram, and Orakzai agency (**Figure 7**). The covered by Khyber agency is 2,576 Sq Km. It consists of three Tehsils, LandiKotal, Jamrud, and Bara. LandiKotal is positioned at 34°6'4N 71°8'44E on the Khyber Pass in the Khyber agency at 1,072 m above sea level. The river Kabul is 700 km in the Sanglakh range of the Hindukush, mountain in Afghanistan, and run through Loy Shalman area of Landikotal Khyber agency and joins the river Indus Pakistan. There are some natural streams which is originated from mountains such Ghar water stream in Ali Masjid, stream of Landi Khana Torkham, some water channel such as Muktarkhel, Ashkel, Perokhel, and Kam Shalman are the natural water reservoirs [92]. The study revealed that physicochemical parameters of the drinking water of the Khyber agency are within acceptable limits. The samples collected from different areas (Landikotal and Jamrud) of the Khyber agency showed that heavy metals Co, Cu, Pb, and Arsenic were found below the prescribed limit. While, the amount of Zn, Fe, and Cr were within the safe limit. However, Cd was found to exceed the safe limit in some samples of this area. The CDI and HQ indices

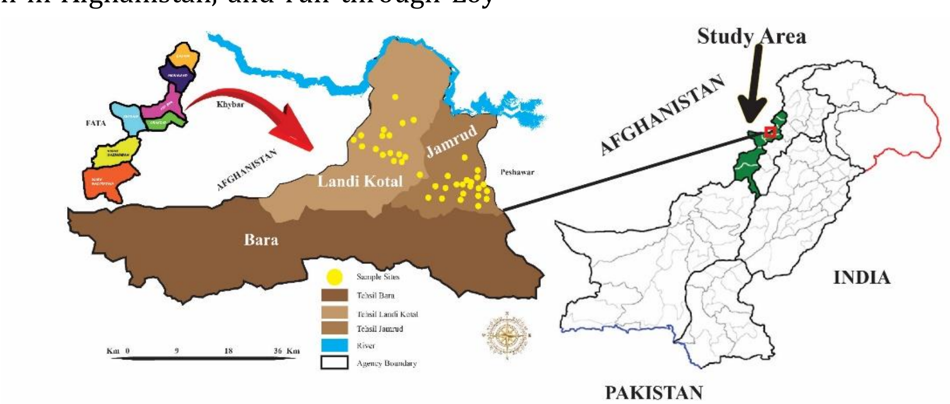
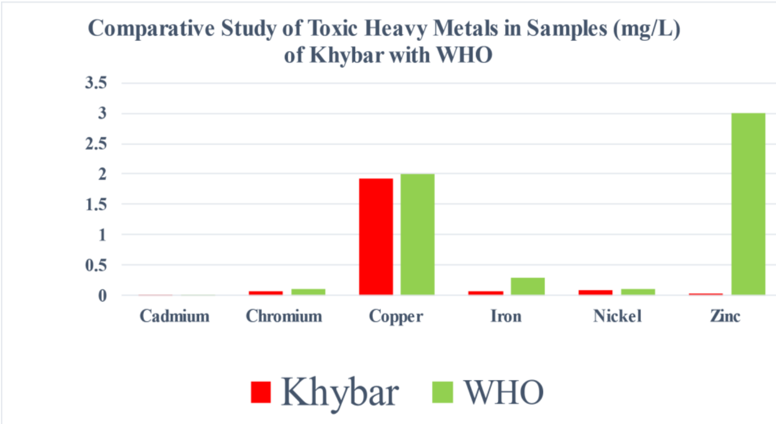


Figure 7. Landikotal and Jamrud (Khyber agency)



Metals	mg/L	
	Khybar	WHO
Cd	0.0021	0.003
Cr	0.07	0.1
Cu	1.923	2
Fe	0.07	0.3
Ni	0.093	0.1
Zn	0.034	3

Figure 8. Comparative study of HMs limit with the WHO (Khyber)

reported the heavy metals in the drinking water of the Khyber agency were in order of Zn > Fe> Cd > Cr and Zn > Cd > Fe > Cr, respectively [93].

The water samples of Tahsil Bara (Khyber agency) showed that the toxic heavy metals adulteration in water according to the acceptable limit given by the WHO were given in ascending order Cu>Ni>Fe=Cr>Zn>Cd (**Figure 8**). All the heavy metals were within safe limit [100].

5.3. Kurram agency

Kurram agency is located at the border (Afghanistan) in FATA (Pakistan). The word ''KURRAM'' is originated from the name of river Kurram. The agency covered area of 115 Km long with an area of 3380 squares Km. The head quarter of the agency is Parachinar at a distance of 74 Km from Thall. The agency lies between North latitudes (33.20 to 34.03) and East longitudes (69.50 to 70.45). Kurram agency is bordered with Afghan provinces in north and west, Orakzai and Khyber Agencies in East, as well as Hangu in south east and North Waziristan in South [94]. The river Kurram spread about 20 Km of Gardez in south east (**Figure 9**). It runs from mountains of north East then enters into Pakistan at 80 km in the south west (Jalalabad) after passing through Koh-e- Sufed (south) drained into river Indus plains in north (Banu), traveling 320 km distance it meets with the Indus river near Essa Khel [95]. Water adulteration of heavy metals was studied in the Kurram river. It showed that the cause of this adulteration including point sources of municipal/industrial wastes and dumping of untreated waste in the river and non-point sources are agrochemicals and

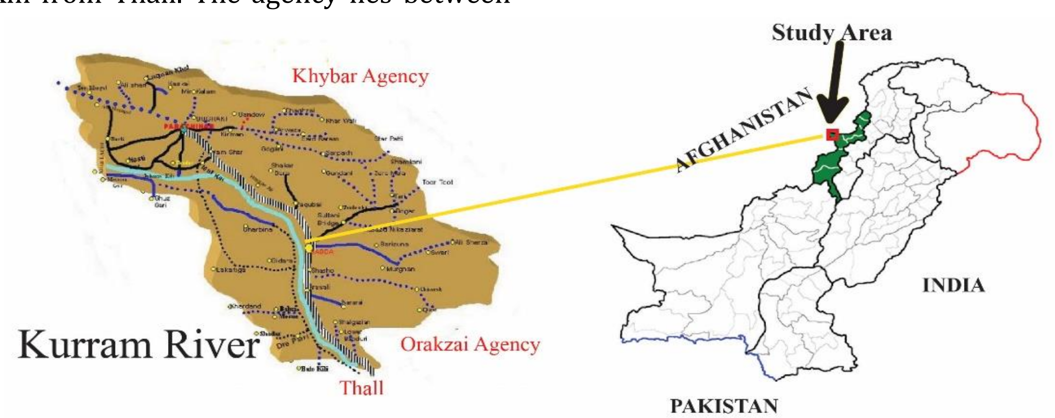
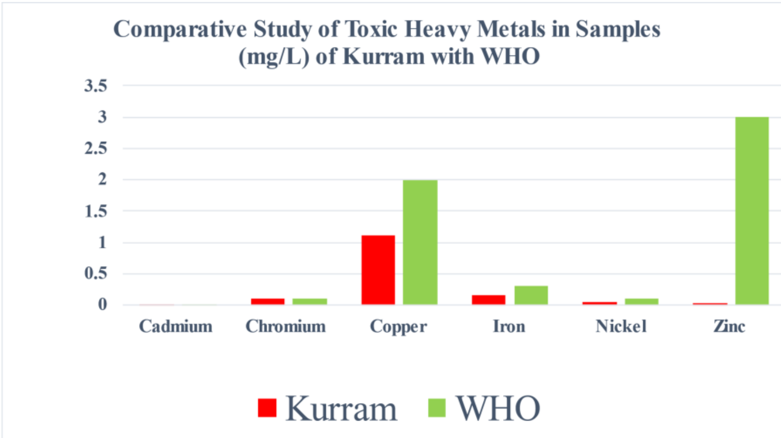


Figure 9. Kurram river (Kurram agency)



Metals	mg/L	
	Kurram	WHO
Cd	0.0014	0.003
Cr	0.1	0.1
Cu	1.106	2
Fe	0.16	0.3
Ni	0.049	0.1
Zn	0.03	3

Figure 10. Comparative study of HMs limit with the WHO (Kurram)

atmospheric depositions. river sediments were more adulterated than water. The samples contained heavy metals following the order of Fe>Cr>Mn>Pb>Cu>Ni>Zn. To protect the aquatic ecosystem and water reserves, there is a need to monitor and follow national environmental quality standards (NEQs) [96].

The water samples of Lower Kurram (Kurram agency) showed that the toxic heavy metals adulteration in water according to the acceptable limit given by the WHO were in order Cu>Fe>Cr>Ni>Zn>Cd. All the heavy metals were in safe limit (**Figure 10**) [100].

5.4. Mohmand agency

The Mohmand Agency is situated in the north of Peshawar (Khyber-Pakhtunkhwa) Pakistan (**Figure 11**). The study area lies between 71°350 to 71°400 longitude East and 34°2203500 to 34°2504000 latitude North. Rainfall is limited mostly in winter. Rocks in this region are part of the Kot-Prang Ghar mélange in Prang Ghar, Bucha, and Nawakille. There is Mafic and ultramafic rocks composed of gabbros, peridotites, dunites and serpentinites. The ultramafic rocks contain chromite ores. People of this region used for agriculture activities. It is observed that plants grown in the soil derived from rocks are contaminated more with Fe, Cr, and Ni [97]. The study area is mainly comprised of Bucha and surrounding areas in Mohmand agency, north of Peshawar, Pakistan which is located between longitudes 71°35′ to 71°38′ E and latitudes 34°20′ 35″ to 34°25′40″ N. Main settlements in the Mohmand agency have valleys along the bank of Kabul River. The water required for irrigation is taken from Kabul and Swat rivers.

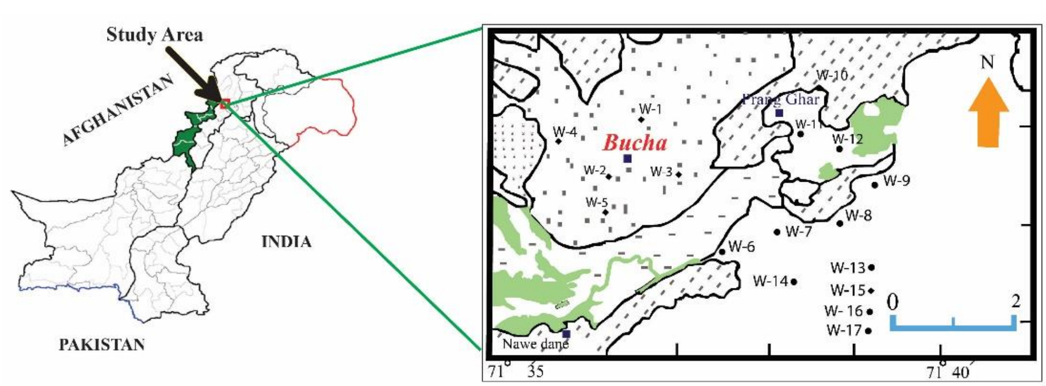
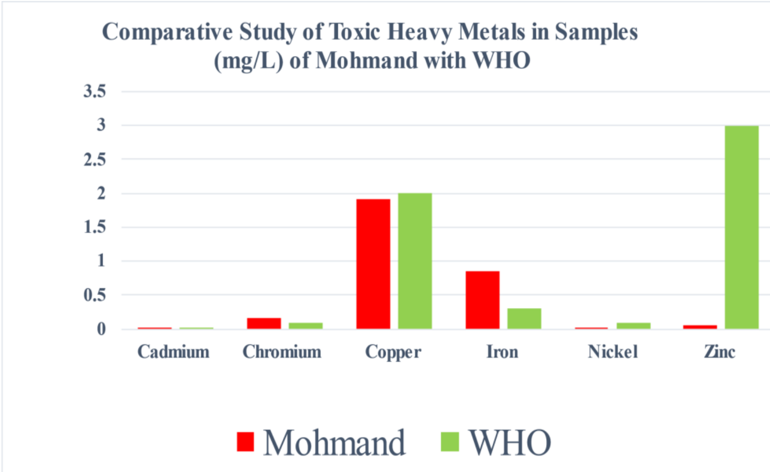


Figure 11. Bucha surrounding area of Mohmand Agency (KPK)



Metals	mg/L	
	Mohmand	WHO
Cd	0.0021	0.003
Cr	0.16	0.1
Cu	1.907	2
Fe	0.86	0.3
Ni	0.019	0.1
Zn	0.055	3

Figure 12. Comparative study of HMs limit with the WHO

Most of the population in the hilly areas used water from streams and springs and dug wells for water use [98]. Industrial waste is one of the major reasons for water adulteration such as toxic heavy metals. In Buner, marble industries are responsible for water adulteration in water reservoirs. Groundwater near the source of adulteration takes time to be contaminated as an aquifer once it gets adulterated it remains for centuries [99].

The water samples of Tehsil Safi (Mohmand Agency) showed that the toxic heavy metals adulteration in water according to the acceptable limit given by the WHO were in ascending order as Cu>Fe>Cr>Zn>Ni>Cd. All the heavy metals were in safe limit except Fe its concentration was greater than the WHO (**Figure 12**) [100].

5.5. North Waziristan agency

Barganat Dam is situated in North Waziristan (FATA), Pakistan, respectively (**Figure 13**). The water of the dam is used for irrigation, fish cultivation, and flood control. The results showed that the parameters ensure the quality of water found in acceptable limit for aquatic life [101]. The North Waziristan is in the west of near Lakky Marwat. The water adulteration in the sources shared by two regions reported are in order Cd>Pb>Cr>Fe>Zn [102]. In Khyber PaktunKhwa District that is Bannu reported the water adulteration, the water with toxic adulteration cause health problems for all living beings. It is important to ensure the acceptable limit of all heavy metals in water reservoirs [103].

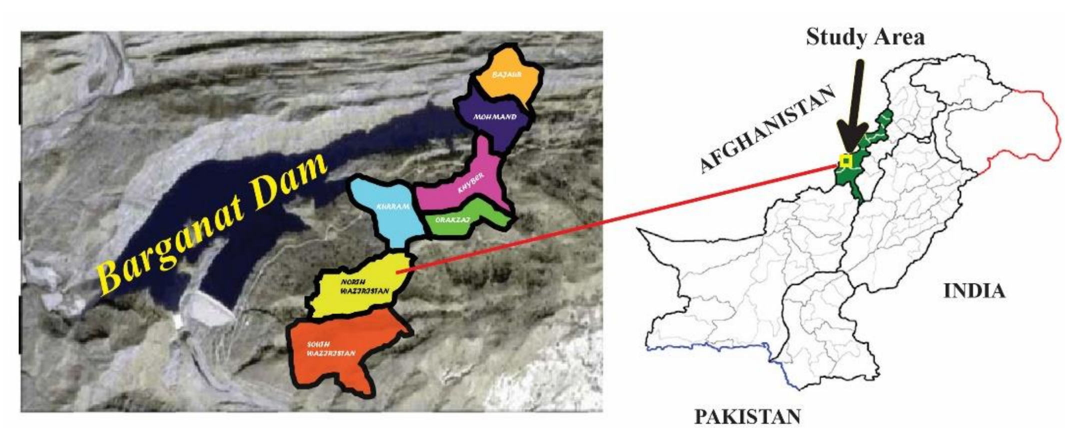
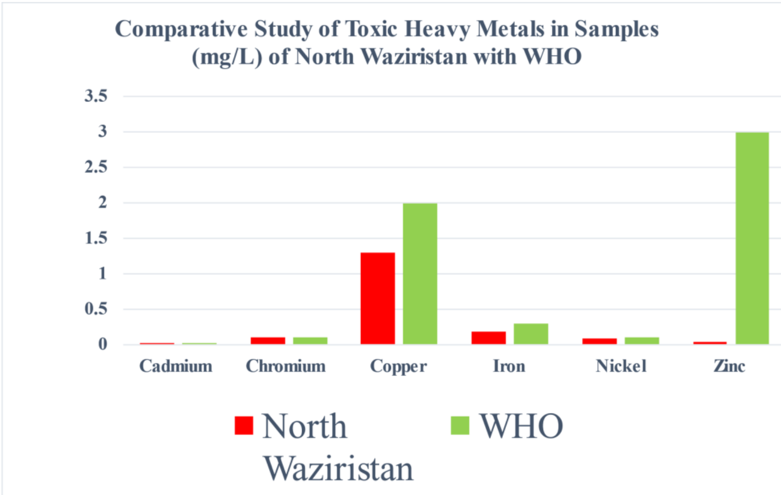


Figure 13. Barganat Dam (North Waziristan) KPK



Metals	mg/L	
	North Waziristan	WHO
Cd	0.0023	0.003
Cr	0.11	0.1
Cu	1.301	2
Fe	0.19	0.3
Ni	0.09	0.1
Zn	0.044	3

Figure 14. Comparative study of HMs limit with the WHO (North Waziristan)

Water samples of Tehsil Miranshah (North Waziristan agency) showed that toxic heavy metals adulteration in water according to the acceptable limit given by the WHO were in order Cu>Fe>Cr>Ni>Zn>Cd (**Figure 14**). All heavy metals were in safe limit except Cr its concentration was greater than the WHO [100].

5.6. South Waziristan agency

Gomel Zam Dam is situated in South Waziristan Agency in the Khjori Kutch lies between Wana and Tank FATA (Pakistan). It is the mega of water reservoir in the FATA(Pakistan). This dam is associated with Gomel River one of the western tributaries of river Indus. The water of the dam is used for irrigation, hydropower, and flood protection. It has the capacity to irrigate 66,000 hectares of land [104]. Besides the all benefits the water of the dam is not use for fish production. Heavy metals including Iron (Fe), Copper (Cu), Zinc (Zn), Nickel (Ni), and Cadmium (Cd) will be analyzed with the help of atomic absorption spectrophotometer [105]. The reported work on fish farming helped to identify the water adulteration. In this regard, lots of work has been done to maintain the water quality of the region [106]. In the South Waziristan Agency of FATA (Pakistan), Dargai Pal Dam is located (**Figure 15**). The dam height is about 84 feet, a covered length of 764 feet, and a storage capacity of water 2178-acre feet [107]. Heavy metals limit and TDS were found to be in suitable limits. Hence, it is good to support aquatic life, especially fish [108].

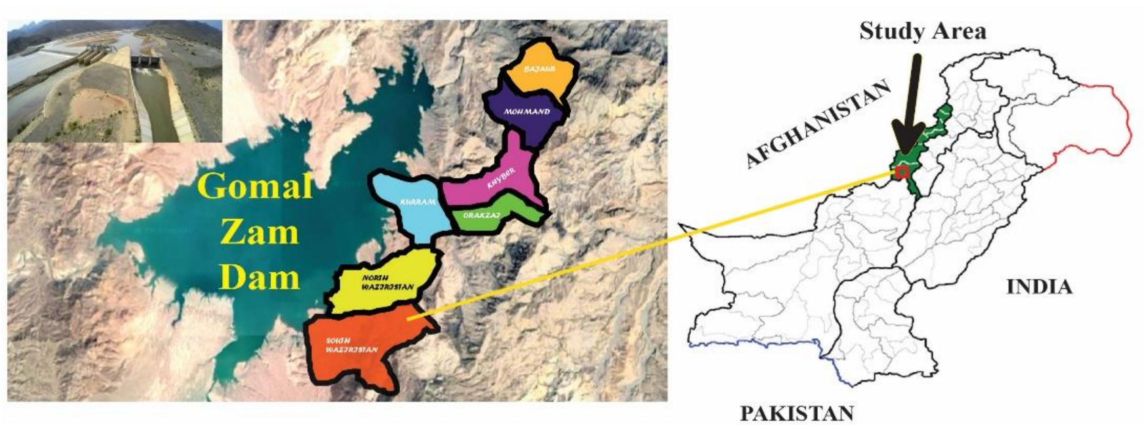
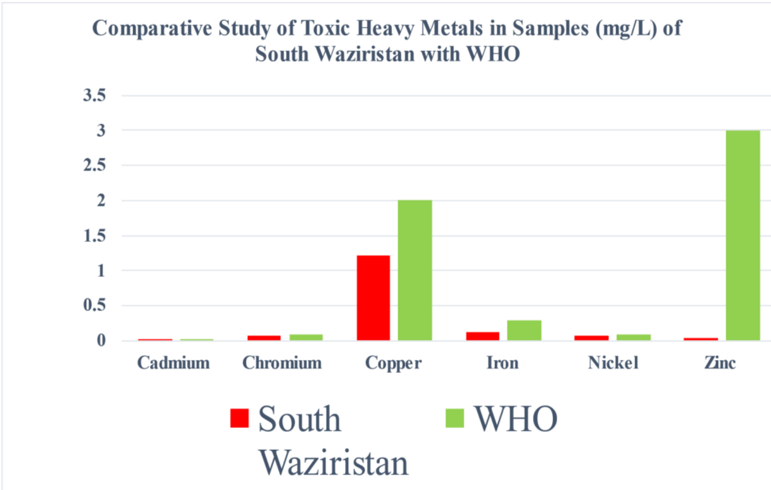


Figure 15. Gomal Zam Dam (South Waziristan) KPK



Metals	mg/L	
	South Waziristan	WHO
Cd	0.002	0.003
Cr	0.08	0.1
Cu	1.219	2
Fe	0.12	0.3
Ni	0.07	0.1
Zn	0.047	3

Figure 16. Comparative study of HMs limit with the WHO (South Waziristan)

Water samples of Tehsil Wana (South Waziristan agency) showed that the toxic heavy metals adulteration in water according to the acceptable limit given by the WHO were in order Cu>Fe>Cr>Ni>Zn>Cd (**Figure 16**). All the heavy metals were in safe limit [100].

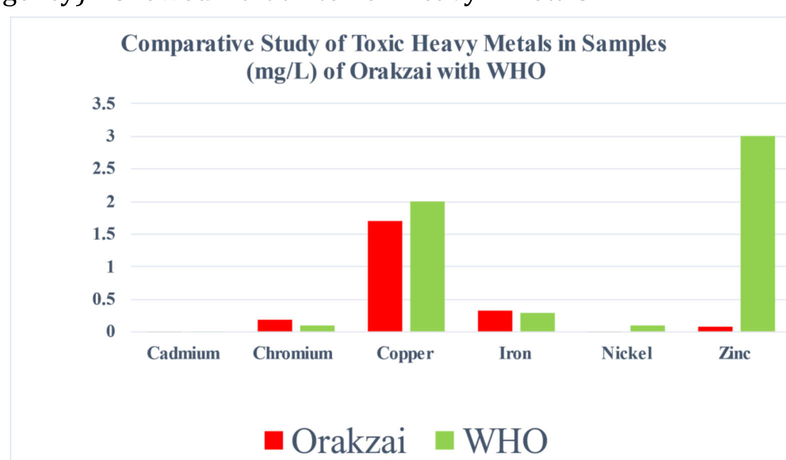
5.7. Orakzai agency

The reported work showed that water of region had the amount of cadmium, chromium, iron, and lead in the prescribed limit while zinc and copper were recorded below the permissible limit. In Orakzai Agency, mining of coal sources as mining is also the source of adulteration in the region [109-111].

The water samples of Lower Orakzai (Orakzai agency) showed that toxic heavy metals adulteration in water according to the acceptable limit given by the WHO were in order Cu>Fe>Cr>Zn>Ni>Cd (**Figure 17**). All the heavy metals were in safe limit except Cr and Fe because concentration of both is greater than the WHO [100].

6. Conclusion

- On account of the research of the authors on different regions of FATA(Pakistan), the drinking water samples contain some heavy metal concentrations more than the safe and desirable levels set by the WHO, EUC, EPA, and USEPA. Most of the water samples were at a level, which is not used for drinking purposes.



Metals	mg/L	
	Orakzai	WHO
Cd	0.0029	0.003
Cr	0.19	0.1
Cu	1.703	2
Fe	0.32	0.3
Ni	0.011	0.1
Zn	0.087	3

Figure 17. Comparative study of HMs limit with WHO (Orakzai)

- The author's article concluded from their work that the water samples need constant monitoring of various water sources as the results showed levels of pollution and significant risk given the toxicity of these heavy metals.
- There is a need for that drinking water in the region should be checked and filtered by the quality control agencies.
- People may suffer from the disease in drinking water containing high concentrations of toxic heavy metals. They may affect the kidney, digestive system, circulatory system, and nervous system of the body.
- In general, in most articles, the concentration of some toxic metals was higher than the safe limit. The reasons for this adulteration were the characteristics of geology, a network of water supply, wastewater, atmospheric depositions, and the industries effluent were also influential. Surface and groundwater sources in some regions of FATA (Pakistan) exceed the standards set by the WHO.
- Heavy metals adulteration of water is a potential threat to living beings. Among the heavy metals, Cd, Ni, Pb, Fe, Cu, Cr, Mn, and Zn, all exceed their standard limits set by the World Health Organization (WHO) in some regions of FATA agencies. The frequent increase in the concentration of these metals in water is an alarming situation.
- The frequent use of agrochemicals in water samples from different areas, human activities mainly disposal of untreated industrial effluent, and municipal wastes are the main sources of water adulteration in FATA (Pakistan).
- Based on the results of the exposed pollution and health risk assessments, it is observed that water surrounding the industrial, areas are adulterated by toxic heavy metals consistently. The risk assessment in terms of HQ and HI reports that water in FATA (Pakistan) is adulterated with toxic metals to a level that constitutes risks in some regions of FATA (Pakistan).
- Assessment of health risk in terms of HI shows that people in most of the studied areas are at risk of the combined effect of toxic metals, through the water. In Khyber Pakhtunkhwa, many areas are risky with respect to heavy metal adulteration in water. However, comparatively little data are available on metal-adulterations health risks in FATA regions because of a lack of proper surveys, poor facilities, no proper diagnosis system, and maintenance of records at hospitals.
- It is very important to reinforce the research work to analyze toxic heavy metals adulteration in water to maintain the water quality according to the standards and protect the potential risks caused by trace elements such as heavy metals.
- The review reveals the quantitative analysis of toxic heavy metals and evidence of impact on living beings that are exposed to them in the different regions of FATA (Pakistan).
- The main conclusions from this comparative study of different water sources (tube wells, open wells, springs, hand pumps, dams, and rivers) in different areas of seven agencies of FATA (Pakistan) that is Bajaur Agency, Mohmand Agency, Khyber Agency, Orakzai Agency, Kurram Agency, North Waziristan Agency and South Waziristan Agency are that the most of the water samples collected from this region of Pakistan were of poor quality and not suitable for drinking due to the elevated level of PTEs.
- The quality of tube wells water is better than the water from springs, rivers, hand pumps, and open wells. Among all the sources springs give comparatively the higher noncarcinogenic risks (HRI) related to concentrations of toxic metals. The total hazard index (HI) for water analyzed from hand pumps was quite close to the toxicity level. However, the tube wells were within the safe limits.
- On the basis of the findings, deep aquifers using tube wells should be used as a source of drinking water.
- The results obtained from analyzing fish organs, native plants, sediments, and water samples give information about toxic heavy metal accumulation. The results showed that most water samples have less toxicity and are safe for all living beings.
- Some samples showed higher concentrations of Fe, Zn, Cu, Cd, Mn, Cr, Pb, and Ni.

- As arsenic, is the most toxic heavy metal it is highly carcinogenic. Fortunately, all samples contained arsenic within the safe limit given by the WHO.
- The level of water adulteration and sediments was examined from up to downstream due to the large distance from sources of contamination and events of dilution. The river sediments were more adulterated by toxic heavy metals as compared to the water samples.
- Statistical data like PCA showed that the accumulation of this adulteration into water samples can be attributed to the weathering and leaching of the mafic and ultramafic rocks and mining of ores in the study areas.
- These areas in northern Pakistan require attention as mental adulteration through geogenic sources is a matter of concern. Further studies need to examine the concertation of toxic heavy metal adulteration in the water of FATA (Pakistan) in detail.
- The main conclusion after the thorough study of research papers is that the water in this region is not carcinogenic and can be used for drinking purposes.

7. Future Prospective

A comprehensive analysis of published data reveals that heavy metals such as cadmium, chromium, lead, manganese, zinc, copper, and iron are found in water samples of different regions of FATA (Pakistan). However, anthropogenic actions contribute significantly to water adulteration. These toxic heavy metals in high concentrations induce harmful effects on all living beings. Several types of research have revealed that toxic heavy metal exposure causes persistent health issues in human populations. The following exhortation is made which may help to control problems of water adulteration in FATA (Pakistan).

- There should be consistent monitoring of the water quality throughout the FATA (Pakistan) including rural and urban areas.
- Facilities should be provided to the local authorities for monitoring the quality of water.
- The intermittent water sources should be shifted to a continuous water supply to avoid adulteration.
- There should be the repair of the old water pipelines that become rusty and damaged.
- To avoid cross-contamination there should be distant sewage and drinking supply lines.
- Adopt the proper wastewater monitoring system. Also, the effluent comes from industries and sewage should be monitored and properly disposed of.
- There is a need for the implementation of laws for the public on the quality of drinking water that is strictly obeyed.
- People should be educated about the significance of safe drinking water. Therefore, awareness programs should be held.
- The public should be aware and guided about the safety measures for water used inside the houses.
- Awareness programs should be held for farmers to educate them about the proper application and monitoring of agrochemicals which are pesticides, and fertilizers to reduce water and soil adulteration.
- It is suggested that properly investigate the toxic heavy metals in water sources to determine health risks caused by exposure to this adulteration.
- The government should make and implement policies to control heavy metals contamination of water reservoirs used for irrigation purposes to reduce health risks.
- Governmental and different organizations in FATA (Pakistan) take initiative to protect the water sources from the adulteration of toxic heavy metals.
- The government should design regular and proper monitoring programs to update about the accumulation and intensity of major toxic-heavy metals in FATA (Pakistan).
- The research work conducted in Pakistan was found to be limited to central Khyber Pakhtunkhwa, Punjab, and Sindh. There is a need for more research work and risk assessment on FATA region.
- The owners of industries should adopt proper metal-containing effluent treatments.
- Eco-friendly fuels should be used in vehicles.
- The judiciary also involved itself in underlining the problems regarding water adulteration, the need for action to manage it,

and taking the initiative along with the government and with the support of industries in the FATA region.

- Academia is an important component of research and development. As such the concerned departments should collaborate with academic institutions in terms of water quality and adulteration levels in water bodies across the region. The information shared can then be used to make a strategy to overcome water adulteration by heavy metals.
- The role of Environmental Protection Departments (EPDs), Tehsil Municipal Administrations (TMAs), and the Pakistan environmental protection Department is very important to make and implement the policies in this regard.
- Amenity of knowledge and technology for the method of treatment of industries effluent is integral, the EPDs and United Nations Industrial Development Organization (UNIDO) should collaborate with the industrial sector to address their concerns.
- Development of projects to access drinking water reservoirs from deep aquifers in the different regions of FATA (Pakistan), where springs may be a good source of drinking water. Proper water distribution systems should be developed across the region to minimize water adulteration by toxic metals.
- To protect dams and rivers from adulteration and prevent aquatic life, monitor and follow national environmental quality standards (NEQs) and avoid dumping of untreated effluent and direct discharge of municipal into the river.
- There is a need to further investigate the water sources in different regions of FATA (Pakistan) and determine the level of toxic heavy metals, especially arsenic.

Acknowledgment

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Orcid:

Riffat Bibi
http://orcid.org/0009-0003-8458-8453
Zahid Muhammad
http://orcid.org/0009-0003-8086-2697
Zaheer Ahmad
https://orcid.org/0000-0001-6989-1620
Fawad Ahmad
http://orcid.org/0000-0003-2404-5572

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