



Drinking Water Quality Assessment of Government, Non-Government and Self-Based Schemes in the Disaster Affected Areas of Khyber Pakhtunkhwa, Pakistan

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Abstract

The present study aimed to investigate the physicochemical parameters, potentially toxic elements (PTEs) and *Escherichia coli* (*E. coli*) contamination with associated health risks in drinking water sources from the disaster affected areas of Khyber Pakhtunkhwa (Pakistan). Total water samples ($n = 120$) were collected from different water distribution schemes, such as non-government organizations (NGOs), government (GOV) and self-based scheme (SBS). The results showed that physicochemical parameters were found to be in decreasing order; NGOs > SBS > GOV in drinking water sources. PTEs concentrations were found to be in order; Zn > Pb > Cu > Cr > Co > Ni > Hg, Cu > Zn > Pb > Cr > Co > Ni > Hg, and Zn > Cu > Cr > Pb > Co > Ni > Hg for NGOs, GOV and SBS, respectively. Hg and Cr in SBS, while Co in GOV and SBS exceeded the WHO and Pak-EPA limits. Hazard quotient (HQ) showed no potential health risk, except for Co and Hg (> 1) in GOV and SBS. Principal component analysis (PCA) revealed high anthropogenic activities and less geogenic sources. The questionnaire survey showed that local communities were highly vulnerable due to poor pipelines system and domestic sewage within the areas of GOV and SBS water sources. Numerous diseases, such as dysentery contributed for (14%, 12%, and 18%), diarrhea (25%, 21%, and 18%), and stomach problems (48%, 33%, and 27%) due to consumption of *E. coli* contaminated water in NGOs, GOV and SBS, respectively, in the study area.

Keywords Drinking water sources · Potential toxic elements · Coliform · Health risk assessment · Northern districts · Pakistan

Introduction

Safe and adequate drinking water supplies have a crucial role to protect the public health concerns worldwide and could substantially prevent diseases risks associated with water consumption (Hunter et al. 2009). The drinking water from specific sources and regions depends on its physical, biological and chemical parameters, which are effective factors to measure and observe the quality of the water for drinking and domestic purposes (Gilani et al. 2013). Water is a precious resource that could be susceptible to potential toxic elements (PTEs) contamination in the environment (Ciazela et al. 2018). The environmental pollution of PTEs and its transportation has rapidly increased in the environment due to urbanization worldwide, since 1940s (Khan et al. 2004). PTEs persist in the environment and cannot be degraded by microorganisms in excessive concentration in the natural environment, thereby contributing to the contamination of food chain and waterbodies. Their ingestion may pose

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diverse health problems (WHO 2014; Wieczorek-Dąbrowska et al. 2013; Xiao et al. 2013). Bacteriological contamination especially the pathogenic *E. coli* also alters and affects the drinking water quality (Radford et al. 2018). *E. coli* contamination in drinking water sources prone to cause potential health risks through consumption, and thereby results in waterborne diseases (Nawaz & Ali 2018). As a result, drinking water shortage, contaminated water and prevalence of microbial contamination has produced adverse health issues in developing countries (WHO 2008). According to the recent report, approximately 2.3 billion people are still suffering from serious waterborne diseases due to contaminated water around the globe (Ahmed et al. 2020). For this reason, the distribution and consumption of such polluted water may lead to continuation of adverse health problems, due to the lack of water quality assessment and improper management.

In ideal situation, pathogens like *E. coli* and total coliforms must be investigated for clean drinking water once in a month for small water body and 480 times for larger water body to be certified potable for consumption and domestic use. However, it is not possible in developing countries due to limited resources (Kostyla et al. 2015). According to WHO (2011), the four key stages including problem formulation, exposure assessment, health effects assessment, and risk characterization are important to scientifically understand the pathogens in water sources and to overcome its persistence, human exposure and reduce the substantial diseases by incorporating their fate and transport rate through the proper system in environment. Hence, a comprehensive study is necessary to understand and investigate the PTEs and pathogenic bacteriological contamination in drinking water sources, its distribution and potential human health risks. Previously, numerous studies have reported the contamination of PTEs and microbial pathogens and their potential sources in drinking water sources of Pakistan and the other parts of the world (Ezemonye et al. 2019; Ji et al. 2020; Liu et al. 2022a, b; Liu et al. 2020; Memon et al. 2011; Muhammad & Ahmad 2020; Nawab et al. 2016; Owens et al. 2020; Ricolfi et al. 2020; Sabir et al. 2017; Wei et al. 2022).

In Pakistan, the clean drinking water shortage and pollution is rapidly increasing due to overconsumption of water and fast population growth, which may lead to alarming condition for the country to be listed in water shortage countries in the near future (Azizullah et al. 2011). It was estimated recently that about 20–40% of the human population of Pakistan are suffering from serious waterborne diseases in Pakistan due to microbial contamination in drinking water sources (Ahmed et al. 2020; Muhammad et al. 2018). Most of the local inhabitants use contaminated water for drinking and for other domestic purposes especially in rural areas. Thus, various waterborne diseases, such as cholera, diarrhea,

hepatitis (A, B, and C), dysentery, and typhoid are mostly common and has been on the increase among the population in Pakistan (Amin et al. 2019; Daud et al. 2017). Khyber Pakhtunkhwa (KPK) province of Pakistan has been disastrously hit within the last two decades by two main tragic incidents (Earthquake in 2005, and Flood in 2010), and Talibanization. KPK was the worst affected province in 2010 in which maximum local people were displaced due to a devastating flood. As a result, the primary services including sanitation system and clean water supply were harshly affected by the flood. Moreover, inhabitants were under severe risk of disease outbreaks due to crowded and worst conditions of the displaced persons, poor sanitation systems, and availability of contaminated drinking water. Numerous waterborne diseases were raised such as cholera, hepatitis (A and E), shigellosis disease, typhoid fever, and other skin diseases related with poor sanitation and consumption of inadequate contaminated drinking water (Khan et al. 2013c). Most of government and non-government organization sectors, including local, national, and international agencies installed a large number of tube wells, bore wells, hand pumps, and pipelines, sanitation system and hygiene (WASH) related projects by providing safe and clean drinking water in the vulnerable communities (Khan et al. 2013b; Nawab et al. 2016, 2018). Despite these efforts, the drinking water quality is still not suitable and safe for the local population. Therefore, this detailed study was conducted (i) to investigate the physicochemical and biological parameters of different water sources, i.e., tap water, springs, wells, tube wells and hand pumps) of three study area schemes including government (GOV), non-government organizations (NGOs), and self-based scheme (SBS), (ii) to study the PTEs (Hg, Cu, Cr, Ni, Cd, Pb, and Zn) and *E. coli* contamination, their distribution, and sources identification of these contaminants by multivariate statistical analyses, (iii) to evaluate their contamination factor (CF), pollution load index (PLI), water pollution index (WPI), and health risk assessment, and (iv) conduct questionnaire survey to present the waterborne disease distribution among different age group in the disaster affected areas of Khyber Pakhtunkhwa, Pakistan.

Materials and Methods

Study Area Description

The study area which comprises eight northern districts is located in the Khyber Pakhtunkhwa province of Pakistan, as shown in Fig. 1. These districts are famous for being mountainous terrains and rich natural resources. The District Buner is located in the northern area of Pakistan within latitudes of 34°9′–34°43′N, and longitudes of 72°10′–72°47′ E. It shares border with district Swabi in the south, Swat

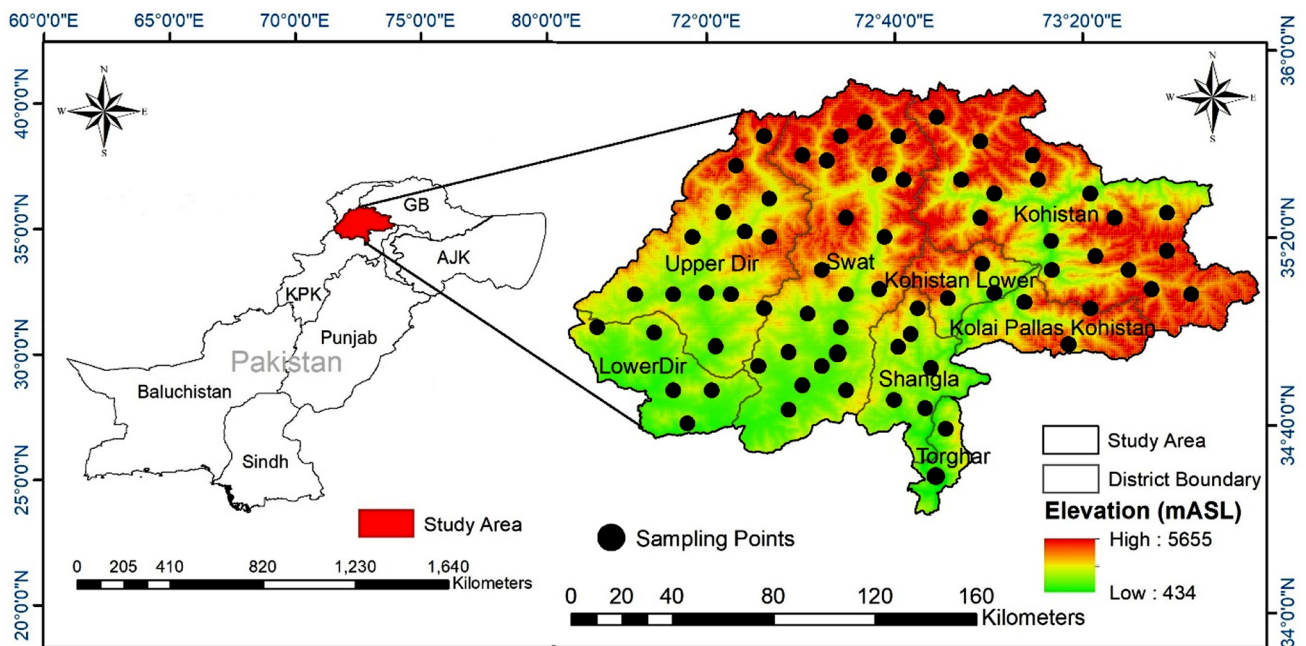


Fig. 1 Map of the study area showing the locations of the sampled districts in KPK

and Shangla districts in the north, Haripur and Mansehra districts in the east, and Mardan and Malakand districts in the west. The industries located in these regions releases enormous amount of wastewater being generated during production processes to the surface water bodies without proper treatment (Nawab et al. 2015). The geological area is mainly composed of intrusive igneous rock containing granites, quartz-syenite, and yenites of different ages (Rafiq et al. 1984).

Swat district, with a total area of about 5337 km², is located within latitudes 34°–36° N and longitudes 71°–73° E and bounded within the Gilgit and Chitral regions. The annual rainfall in the Swat district ranges between 750 and 1350 mm (Shah et al. 2010). The Lower and Upper Dir districts are adjacently located and shares their boundaries with Afghanistan, Swat, Chitral, Malakand and Bajaur, and the overall populated area is 120 per square mile. Swat River, local natural springs and bore wells are usually used as a drinking water source for domestic and agricultural purposes (Khan et al. 2013a). Then the river passes through the entire Swat district and enters the Dir district at Chakdara and reaches to Panjkora River at lower Dir and finally passes through Malakand Agency. Panjkora River is considered as a major tributary in these two districts, originating from Kohistan and flow through the Lower and Upper Dir district (Muhammad et al. 2014). The Swat region hosts green forests with steep mountains and hills, meadows and natural streams. The geology of the area contain doiomitic marble, graphitic phyllite marble, schistose marble, feldspathic

quartzite and calcareous schist (Dipietro et al. 1993). Nowadays, water pollution is a serious issue in Swat River due to high industrialization, urbanization, intensive agricultural practices, tourism, traffic emission and waste discharge from the municipality and adjacent hotels on riverbanks.

The Shangla district is located at latitude of 34° 53' 12" N and longitude 72° 36' 00" E. The district is surrounded by main regions, such as Swat, Kohistan, Battagram, and Buner in the south of KPK province. The total area of the Shangla district is 1586 km² and covered with rich natural floras and faunas. The Kohistan district is located between latitudes 34°50'–35°12' N, and longitudes 72°30'–73°5' E. Springs, streams and Indus River are the main sources of water used for drinking, domestic consumption as well as for agricultural purposes by local people of Kohistan district. Indus River is flowing through the whole Kohistan area and divides into the Hazara Kohistan and Swat Kohistan. Kohistan regions contain intrusive rocks of Kamila amphibolites belt, Chilas complex and Jijal complex as well as Kohistan batholiths. The mafic and ultramafic rocks of the Kohistan area are mainly exposed in Jijal and Dubair areas (Majid 1985). The Torghar district is located between latitudes 34°32'–34°50' N, and longitudes 72°48'–72°58' E in KPK. This region has mountainous rugged slopes, with a total area of about 800 Km² (Shah et al. 2015). Moreover, the district consists of subalpine meadow lands, hilly forest and rivers spread in the high lands. The plain areas of northern districts are warmer in summer (32 °C), as compared to regions with high altitudes and become cold in winter season

(− 2.4 °C). Local inhabitants use water from open wells, hand pumps, tube wells and water springs for drinking and domestic purposes in these northern regions.

Sampling and Analytical Procedures

A total of 120 water samples were collected in the study area between 2018 and 2019, from numerous water sources including (tap water, springs, wells, tube wells, and hand pumps) installed by GOV, NGOs, and SBS schemes in the study area. Water samples were collected from these sources with polyethylene bottles. In order to avoid pre contamination during sampling, the water taps were opened and hand pumps were pumped for 2–5 min (Khan et al. 2013c). The bottles were filled with water and then discharged and filled again with fresh water samples to remove the air from the bottles (Khan et al. 2013c). All the water samples were acidified with (5%) HNO₃ to inhibit the microbial growths in water. All the water samples were then stored in cool dark place and transferred to laboratory for further analysis. Moreover, standard methods were used for analysis of physicochemical parameters such as total dissolved solids (TDS), pH, electrical conductivity (EC), temperature, and nitrate (NO₃), as procedures adopted by (Khan et al. 2013c). During the sampling, pH of water samples was measured in situ using portable battery-activated pH meter (Model WAG-WE30020, Team Valley Gates head NE110NS, UK), while temperature, EC, and TDS were determined in the laboratory using thermistor thermometer, conductivity meter (Model HI 98303), TDS meter (Model S 518877), respectively. Furthermore, the taste, odor, color, and turbidity of the samples were observed on site and were compared with the standard limits of WHO (2011) and Pak-EPA (2008).

The concentration of PTEs, such as Hg, Cu, Cr, Ni, Co, Pb, and Zn were investigated in all water samples from the various schemes (acidic and filtered samples), using graphite furnace atomic absorption spectrometer (GFAAS-700 Perkin Elmer, USA). The PTEs analyses were carried out at the Central Resource Laboratory of the University of Peshawar. *E. coli* bacteria was analyzed in drinking water samples by membrane filtration method of Delagua portable incubator (Wagtech International Potatest WE10005, Team Valley Gates head NE110NS, UK). For analysis of *E. coli*, (100 ml) water sample were penetrated by adding sterile cellulose membranes (nitrate/ester) (47 mm diameter, 0.45 μm pore size, GE Healthcare Life Sciences, Little Chalfont, UK). The membrane was placed on m-fecal coliform media of agar plates 2 (Difco, Franklin Lakes, NJ, USA), for the total incubation period of 24 h at temperature ranged between 37 and 45 °C. Microliter plates built on the presence/absence tests after 24 h, and were used for calculation of most portable number (MPN) of *E. coli* (Xiao et al. 2013).

Pollution Identification

Contamination Factor (CF)

The CF is degree of contamination in water based on the concentrations of some selected PTEs in polluted and background sites (Shah et al. 2010). The CF values were calculated by the given equation below (1):

$$CF = C_{\text{metal}}/C_{\text{background}} \quad (1)$$

where C_{metal} is the concentration of PTEs, and $C_{\text{background}}$ is the concentration of PTEs in the control background sites of water samples. The different CF observed values indicates the contamination level of water samples, such as the $CF > 6$ values represents high level of contamination; $3 \leq CF \leq 6$ exhibits significant high contamination; $1 \leq CF \leq 3$ shows moderate contamination, while $CF < 1$ presents low contamination of water samples (Abdullah et al. 2011).

Pollution Load Index (PLI)

PLI is used to estimate the PTEs pollution level in water samples of the study area. The PLI calculation is based on the observed contamination factor of PTEs in water. The following Eq. (2) was used to calculate the PLI (Ra et al. 2013).

$$PLI = \sqrt{CF_1 \times CF_2 \times CF_3 \times \dots \times CF_n} \quad (2)$$

where CF represents the contamination factor, and n is the number of PTEs. The PLI value (< 1) specifies no significant contamination level, and $PLI > 1$ shows the contamination of water exists in the study area.

Water Pollution Index (WPI)

WPI were used to estimate the pollution load in water samples of all schemes (NGOs, GOV, and SBS) of the study area, based on the standard permissible limits as represented by the WHO (2011). For this purpose, WPI was calculated for 13 water quality parameters. WPI can be calculated by the following formula Eq. (3).

$$WPI = 1/n \sum_{i=1}^n PLI \quad (3)$$

where n is the number of total parameters that were combined to calculate the contamination load. The WPI categorized the water contamination into four classes. $WPI < 0.5$ value indicates the excellent water quality; $WPI 0.5$ to 0.75 value shows good water quality; $WPI 0.75$ and 1 presents moderate polluted water; and $WPI > 1$ value indicates high polluted water (Hossain & Patra 2020).

Health Risk Assessment

PTEs can enter into the human body through direct and indirect means like inhalation, dermal contact and food ingestion (Khan et al. 2013c; Nawab et al. 2016). Health risk assessment were identified according to United States Environmental Protection Agency (USEPA 2011), with average daily intake (ADI), and hazard quotient (HQ) of PTEs for adults and children. ADI values were calculated with the following Eq. (4) (Ahmed et al., 2019; Ahmed et al., 2020; Liu e al., 2021)

$$ADI = C_m \times DI/BW \quad (4)$$

where C_m is PTEs concentration in drinking water schemes (mg L^{-1}), and DI represents average daily intake of drinking water, such as 1 L/day of water for children, and 2 L/day for adults were used (USEPA 2011). Although BW indicates the average body weight of 72 kg for adults and 32.7 kg for children were used (Nawab et al. 2015).

Hazard quotient (HQ) for selected PTEs were calculated by dividing the ADI values on reference dose (RfD) (Ahmed & Mokhtar 2020a). HQ was calculated using the given Eq. (5) (Ahmed et al. 2019; Nawab et al. 2015).

$$HQ = ADI/RfD \quad (5)$$

RfD values were used to estimate the HQ for PTEs, such as, the reference dose for Cu, Cr, Hg, Zn, Ni, Co, and Pb were 37.0, 1500, 0.3, 300, 20.0, 20.0, and 36.0 $\mu\text{g}/\text{kg}/\text{day}$, respectively (Khan et al. 2013a, b, c).

Questionnaire Survey

A team of environmentalists administered well-structured questionnaires to the local people in the study area. The aimed of the survey was to get information and give awareness about hygienic conditions and to ascertain the occurrence and dominance of many infectious, waterborne and communicable diseases. Different members were interrogated for information collection (hygiene, sanitation, and water storage and collection practices). All the requisite questionnaires were completed in 49 local visits, from September 2018 to December 2018.

Statistical Analysis

Descriptive statistical analyses such as mean, range and standard deviation were calculated by (Statistics 8.1) software, and Microsoft Excel 2010. All the figures and graphs were illustrated using Origin (version 8.0). Arc-GIS (version 10.5) software was used for site map of the study area. R language was used to determine correlation between variables.

Although source apportionment of all the parameters contamination was identified by principal component analysis multiple linear regression (PCA-MLR) by SPSS (IBM, 16.0 version).

Correlation Analysis

The correlation analysis was carried out to identify relation among physicochemical parameters based on the Pearson's correlation coefficient (Wu et al. 2014). Pearson's correlation coefficient (r) can be calculated according to formula (6).

$$r = \frac{\sum_{i=1}^n (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^n (x_i - \bar{x})^2} \sqrt{\sum_{i=1}^n (y_i - \bar{y})^2}} \quad (6)$$

where r is the correlation coefficient of the two physicochemical parameters (x and y). The x and y represent the variables means. The correlation coefficient values range from -1 to 1 . $r < 0$ indicates a negative correlation between the variables x and y , and $r > 0$ shows a significant positive correlation between x and y . Although $r = 0$ implies no correlation among the two selected variables. Overall, the correlation coefficient of the two variables is based on the low, medium, and high correlation between variables.

Principal Component Analysis Multiple Linear Regression (PCA-MLR)

PCA-MLR is a multivariate statistical tool that can be used to describe the important information to extract the factors from various variables in dataset (Duan et al. 2016; Li et al. 2021; Wu et al. 2020). PCA can be used to transform and reduces the multivariate datasets into simple ones with a fundamental structure within the data. PCA was applied to observe the factors following the Kaiser criteria, and eigenvalues should be > 1 with the total variance $> 75\%$ supported by the extracted factors (Wu et al. 2014). PCA-MLR can be expressed by the following Eq. (7):

$$y = b_0 + b_1x_1 + b_2x_2 + \dots + b_mx_m + \epsilon \quad (7)$$

where y is the dependent variable, $x_1 \dots x_m$ indicate the independent variables. $b_0 \dots b_m$ shows the coefficients regression while E signifies the observed random error (Wang et al. 2020).

Quality Assurance and Quality Control

For quality control of standard solution and analysis of PTEs, double distilled water and certified standard solution

(1000 mg/L) of Fluka Kamica (Buchs, Switzerland) were used. The integration in delay time was used as five seconds during analysis in atomic absorption spectrometer (AAS). The analytical chemical spectroscopic purity (Merck Darmstadt, Germany) of 99.9% was used for the sample formation and PTEs analysis. The reagent blanks, duplicate samples, and standards of different concentrations were used. The reproducibility of analytical data was within 5% and analytical estimated error was less than or equal to 10%.

Results and Discussions

Physicochemical Characteristics of Parameters

The physicochemical of parameters in the water samples studied showed less variation in all schemes, as shown in Table 1 and Figs. 2a, b, and c. The mean values of pH (7.6, 7.4, and 7.5) were observed in all the studied schemes (SBS, NGOs and GOV), respectively, of the study area (Fig. 2a). All the pH values were observed in an increasing order GOV < NGOs < SBS. The maximum pH values 7.8, 8.0, and 8.0 were detected in Shangla, Kohistan and Swat districts, whereas minimum pH values 7.2, 6.6, and 6.8 were observed in water samples from all sources of district Lower Dir, Upper Dir and Kohistan, respectively in SBS, NGOs, and GOV schemes, respectively. The pH values were found to be within the acceptable permissible limits given by WHO (2008), USEPA (2011), and Pak-EPA (2008). However, the pH values were observed higher than

the previous study conducted by (Khan et al. 2013b). The results showed that pH values were found to be in normal range of drinking water sources, i.e., 6.6 to 8.0, relatively with acceptable standards ranging from (6.5 to 8.5) at 25 °C, that could be suitable for drinking water purposes (Pak-EPA 2008), and pH content may vary from source to source of water, types of contaminants and bedrocks in river, stream, lake and underground water, which indicates the important water quality factor in drinking water sources. Moreover, pH with high range in drinking water sources could cause bitter taste as well as it affects the water quality and results in water pollution (Paule-Mercado et al. 2016).

The result showed low TDS concentrations with mean values of 0.23, 0.32, and 0.35 mg L⁻¹ in NGOs, SBS, and GOV, respectively and were found in decreasing order of: NGOs > SBS > GOV, respectively (Fig. 2b). The maximum mean value of TDS (0.90 mg L⁻¹) was observed in Buner district for SBS, followed by Upper Dir (0.73 mg L⁻¹), and GOV scheme, respectively. The minimum mean value of TDS (0.01 mg L⁻¹) was recorded in the Kohistan and Upper Dir districts, when compared with the other districts. All the TDS concentrations in the water samples were found to be within the safe standard limits set by USEPA (2011), and WHO (2008), and Pak-EPA (2008). The TDS concentrations were observed to be lower in drinking water sources, than the previous studies of Ghani et al. (2022). However, the presence of high TDS usually depends on the dissolution of major cations and anions, including (carbonates, bicarbonates, chlorides, manganese, potassium, nitrates, magnesium, organic matter, salt, calcium, and other elements)

Table 1 Concentration of *E. coli* and physical parameters in drinking water schemes of the study area

Parameters	Statistics	NGOs (<i>n</i> =40*)	GOV (<i>n</i> =40*)	SBS (<i>n</i> =40*)	PAK-EPA (2008)	US-EPA (2011)	WHO (2008)
<i>E. coli</i>	Range	1.0–2.0	1.0–5.0	1.0–6.0	0/100 ml	0/100 ml	0/100 ml
	Mean	1.80	2.00	2.18			
	S.D	0.44	1.41	1.72			
pH	Range	6.60–8.0	6.80–8.0	7.20–7.8	6.5–8.5	6.5–8.5	6.5–8.5
	Mean	7.46	7.51	7.6			
	S.D	0.35	0.24	0.15			
TDS	Range	0.01–0.63	0.08–0.73	0.11–0.9	–	–	1000
	Mean	0.23	0.32	0.35			
	S.D	0.12	0.16	0.20			
EC	Range	0.30–1.27	0.16–1.46	0.21–1.8	–	–	–
	Mean	0.48	0.64	0.73			
	S.D	0.24	0.33	0.44			
NO ₃	Range	12.20–51.5	7.20–55.6	9.30–58.1	50 mg L ⁻¹	10 mg L ⁻¹	50 mg L ⁻¹
	Mean	25.9	29.7	31.2			
	S.D	11.3	14.0	14.3			
Turbidity		> 5 NTU in all samples			> 5 NTU	> 5 NTU	> 5 NTU

n Number of water samples, *SD* Standard Deviation, *BDL* Below detection limit. (*): Seven Districts of the study area (District Upper and Lower Dir, Swat, Shangla, Kohistan, Torghar, and Buner)

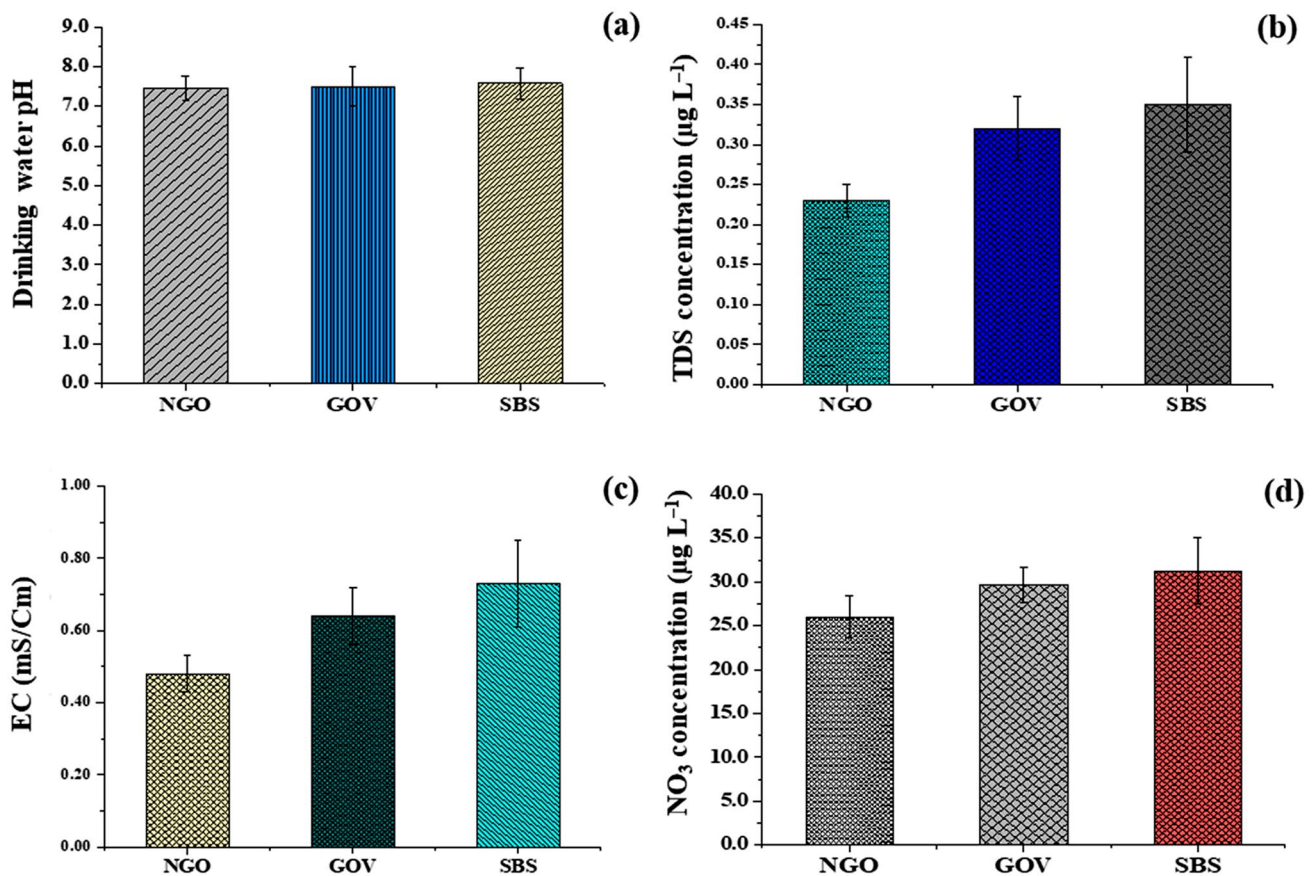


Fig. 2 Mean concentrations of **a** pH, **b** TDS, **c** EC, and **d** NO₃ in all schemes of the study area

(Paule-Mercado et al. 2016). The results also showed that EC occurred in low concentration in all districts water sampled sources of the study area schemes. For all schemes, the EC had mean values of (0.48, 0.64, and 0.73) $\mu\text{S}/\text{cm}$ in order of NGOs < GOV < SBS, respectively, as shown in Fig. 2c. The maximum EC (1.27, 1.46, and 1.88 $\mu\text{S}/\text{cm}$) values were measured in district Kohistan, Swat and Buner, respectively. Although the minimum EC ($\mu\text{S}/\text{cm}$) level were (0.30, 0.16, and 0.2 $\mu\text{S}/\text{cm}$) in the Buner, Upper Dir and Lower Dir districts, respectively for all the studied schemes. Turbidity was also observed to be very low in all the studied schemes (generally < 5 NTU), and were found below the standard limit (< 5 NTU) set by WHO (2008), USEPA (2011), and Pak-EPA (2008). Low turbidity level shows the purity of drinking water sources, while its higher concentration may cause undesirable effects in water and could favor the growth of pathogens that causes various diseases (Jehan et al. 2019).

Another important parameter tested for is NO₃. The NO₃ concentration in the tested water samples ranged from 9.30 to 58.1, 12.2–51.5, and 7.20–55.6 mg L^{-1} , with mean values of 31.2, 25.9, 29.7 mg L^{-1} , observed in SBS, NGOs, GOV, respectively (Table 1 and Fig. 2c). However, the minimum and maximum mean concentrations were observed in SBS

and GOV schemes. The results showed that most of the NO₃ concentration in water samples were above the acceptable limits of USEPA (2011), A total of 10% in SBS, 8% GOV, and 5% NGOs samples exceeded permissible limits of NO₃ concentration of the tested samples by WHO (2008), and Pak-EPA (2008) for springs, open wells, and hand pumps drinking water. The high content of NO₃ contamination indicates the main sources of septic tanks leakage, animal manure, fertilizer use and soil tillage etc. Diseases, such as birth defects, cancer, thyroid, and other numerous health problems are linked with higher concentration of NO₃ (Azizullah et al. 2011). The high NO₃ concentration can also be attributed from emission sources of nitrogen from marble industries, and agricultural practices in the study area. Furthermore, the maximum level of NO₃ detected in SBS scheme in the Kohistan and Swat districts could be associated with the use of nitrogen fertilizers for effective crop production in the regions, which can contaminate drinking water sources. The discharge of nitrogen fertilizer from crop land into the surface and leachate to groundwater bodies have also been found in the previous study of (Howarth 2008). In GOV and NGOs schemes of district Dir and Kohistan, the discharge of farmhouses/livestock wastewater

is attributed primary source of water contamination. The discharge of wastewater from marble industries to various water bodies were found significantly the Swat district. In addition, manure contaminated runoff from agricultural lands, dairy farms and excessive use of fertilizers resulted in NO_3 contamination, while their high exposure can cause methemoglobinemia (blue baby syndrome) in humans (Gupta et al. 2000).

Relationship Between Different Parameters

The relationship between selected parameters in the different assessed schemes (GOVs, NGOs, and SBS) was identified through R language. The R language analysis indicates a strong positive relation between TDS and EC with correlation coefficient of 1.000 ($p < 0.001$) for GOV, 0.97 ($p < 0.001$) for NGO, and 0.96 ($p < 0.001$) for SBS schemes, respectively, as shown in Fig. S1a. (Sawyer et al. 1994) observed the same strong positive correlation between EC and TDS for fresh water. The strong relationship between TDS and EC is due to the type and nature of the dissolved cations and anions in the water. Moreover, weak negative correlation has been observed between TDS (EC) and turbidity in GOVs (-0.24 , $p < 0.05$), while no significant relation was observed in NGOs and SBS scheme. Also there was moderate positive relationship were observed between TDS, Cr (0.42 , $p < 0.01$) and pH (0.45 , $p < 0.01$) and between Pb and TDS ($0.47 < 0.05$) in NGOs scheme, meanwhile in SBSs scheme a weak negative correlation was observed between

TDS and Cr (-0.05 , $p < 0.05$) and no significant relation were observed between TDS and PH, also no significant correlation was observed between TDS, PH and Cr in GOVs scheme. A moderate positive correlation exists between Hg and Co (0.43 , $p < 0.01$) and significant positive between Hg and Cr (0.55 , $p < 0.001$) in GOVs and weak positive correlation between Hg and Cr (0.36 , $p < 0.05$) in NGOs and positive correlation between Hg and CO (0.35 , $P < 0.05$) were observed in SBS scheme. Furthermore, a strong positive correlation was found in all schemes between CO and Cr 0.83 ($p < 0.001$), 0.8 ($p < 0.001$) and 0.79 ($p < 0.001$) in GOVs, SBS and NGOs, respectively. A positive correlation observed between Ni and Pb (0.49 , $p < 0.01$) while in SBS a negative correlation was observed (-0.37 , $p < 0.05$) and no significant relation were found in NGOs scheme. Meanwhile a moderate correlation between Pb and Cr with correlation coefficient of 0.49 ($p < 0.001$) for NGO and 0.36 ($p < 0.005$) for SBS schemes, while no significant relation was observed in GOVs as detailed is given in Figures S1a, S1b, and S1c.

Distribution of PTEs and *E. coli* Contamination in all Schemes

The characteristics and distribution level of PTEs in all the studied schemes are presented in Table 2, and Fig. 3. The Ni had low to moderate concentration level and varied from 1.60 to 37.9, 2.20–42.2, and 6.21–52.3 $\mu\text{g L}^{-1}$, with mean values of 12.5, 14.5 and 17.0 $\mu\text{g L}^{-1}$ for the NGOs, GOV and SBS schemes, respectively. The Ni concentrations were

Table 2 Concentration values of studied PTEs in all schemes of the study area

Parameters ($\mu\text{g L}^{-1}$)	Statistics	NGOs ($n=40$)	GOV ($n=40$)	SBS ($n=40$)	PAK-EPA (2008)	WHO (2008)
Cu	Range	1.40–6.6	0.03–40.0	0.600–5.25	2000	2000
	Mean	2.97	3.54	2.72		
	SD	1.06	6.04	1.39		
Cr	Range	0.60–2.0	0.70–13.5	3.95–81.5	50	50
	Mean	1.19	5.13	12.1		
	SD	0.35	4.39	11.7		
Hg	Range	0.30–5.0	0.5–5.0	0.20–16.0	1	6
	Mean	1.58	1.68	4.15		
	SD	1.19	0.98	3.64		
Zn	Range	9.50–980	43.21–1460	14.15–1624	5000	3000
	Mean	238	323	497		
	SD	247	321	414		
Ni	Range	1.60–37.9	2.20–42.2	6.21–52.3	20	70
	Mean	12.5	14.5	17.0		
	SD	8.47	10.1	7.52		
Co	Range	7.90–36.6	13.80–163	13.58–280	50	50
	Mean	18.4	29.4	43.4		
	SD	7.11	23.6	41.0		
Pb	Range	0.20–3.50	0.25–4.41	0.12–9.81	50	10
	Mean	1.67	1.88	2.70		
	S.D	0.89	0.96	2.08		

n Number of samples, SD Standard deviation

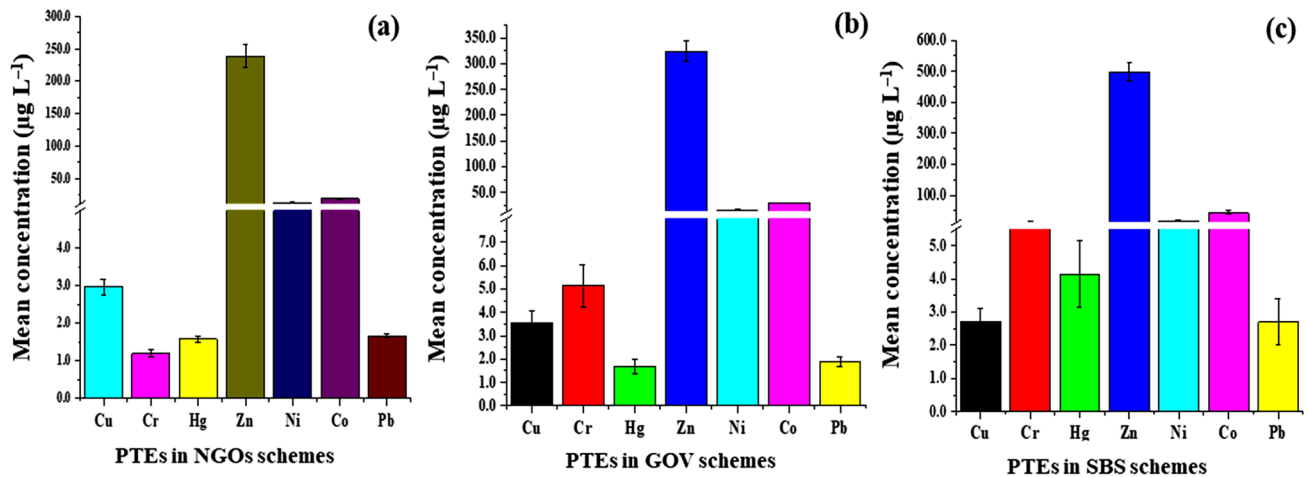


Fig. 3 Contamination level of PTEs in **a** NGOs, **b** GOV, and **c** SBS schemes

found lower than the permissible threshold limits of WHO (2008), and Pak-EPA (2008). In the present study, Ni concentrations were found to be lower than the previous study conducted by (Khan et al. 2011) on drinking water sources in Peshawar city of Pakistan. The low content of Ni in all drinking water sources could be associated with low dissolution of ultramafic rocks in the area (Duda-Chodak & Blaszczyk 2008). In contrast, the Zn and Co were observed in high concentrations than the other PTEs ranged from 9.5 to 980, 43.21–1460 $\mu\text{g L}^{-1}$, and 14.1–1624 $\mu\text{g L}^{-1}$, and 7.90–36.6, 13.8–163, and 13.5–280 $\mu\text{g L}^{-1}$ with their mean values of 238, 323, and 497 $\mu\text{g L}^{-1}$, and 18.49, 29.41, and 43.4 $\mu\text{g L}^{-1}$ in all drinking water sources of NGOs, GOV, and SBS, respectively (Table 2; Figs. 3 and 4). Higher PTEs (Zn and Co) contamination in drinking water sources of tube wells, hand pumps and open wells could have resulted from anthropogenic sources of domestic wastes, agriculture runoff, and poor drainage system (Daud et al. 2017; Rajkovic et al. 2008). The concentration of Zn, and Co were found to be below the acceptable limits of WHO (2008), and Pak-EPA (2008). Although their higher concentration and toxicity can cause health problems like pneumonia, cough, asthma, vomiting, everlasting disabilities, shortness of breath, and ultimately death (Atashi et al. 2009).

In contrast, Pb, Cu, and Cr showed low concentrations level with mean values of 1.67, 1.88, and 2.70 $\mu\text{g L}^{-1}$, 2.97, 3.54, and 2.72 $\mu\text{g L}^{-1}$, and 1.19, 5.13, and 12.1 $\mu\text{g L}^{-1}$ for all drinking water sources in NGOs, GOV, and SBS, respectively. Pb and Cu concentrations in all water samples were below the permissible limits of WHO (2008), and Pak-EPA (2008). The lowest mean concentration of Cu (2.72 $\mu\text{g L}^{-1}$) was detected in SBS scheme, while the highest Cu mean concentration (3.54 $\mu\text{g L}^{-1}$) was recorded in GOV scheme of the Shangla district. The Cu mean concentrations in all the drinking water schemes were found lower than the recent

study of Bhatti et al. (2022). Moreover, Cr had the lowest mean concentration (1.19 $\mu\text{g L}^{-1}$) in NGOs scheme of Lower Dir district, whereas its high concentration (12.1 $\mu\text{g L}^{-1}$) was detected in SBS of the Torghar district. Long-term exposure of human beings to Cr would create health problems, such as skin and liver damages, breathing difficulties, kidney and immune system deformities, and its accumulation in aquatic life can also affect the fishes, and therefore harmful for humans via consumption (Pandey et al. 2010). Comparatively, Cr concentrations were lower than the previous study of (Nawab et al. 2016), and (Liu et al. 2020). About 17% of Cr concentration was higher than the standard limits of Pak-EPA (2008), and WHO (2008) in the SBS schemes. However, Cr is very toxic even in less concentration. Pb had moderate concentrations, and its sources could be lead-based paint, exposure to Pb can cause toxicity in children (Khan et al. 2011). The other element Hg had low mean concentrations (1.58, 1.68, and 4.15 $\mu\text{g L}^{-1}$) in all the studied schemes (NGOs, GOV, and SBS, respectively). The lowest Hg (1.58 $\mu\text{g L}^{-1}$) was detected in NGOs and high (4.15 $\mu\text{g L}^{-1}$) concentration was recorded in SBS schemes of the Shangla District, and Hg exceeded the WHO (2008) permissible limit in some of the samples in SBS schemes. About 90% of NGOs and 5% of GOVs samples were found below the permissible limit of Pak-EPA (2008), and WHO (2008), respectively as shown in Table 2. High level exposure to Hg may affect the brain, kidney, and developing fetuses (Siddiquee et al. 2015). In the present study, it was observed that Hg concentration was relatively higher than the study conducted by Khan et al. (2013b), and (Nawab et al. 2022). In addition, high PTEs (Zn, Co, Hg, and Cr) concentrations in the present study could be associated with the high pH level of drinking and springs water, that stimulates the dissolution of PTEs from natural geogenic sources into the drinking water sources (Khan et al. 2021). The mean

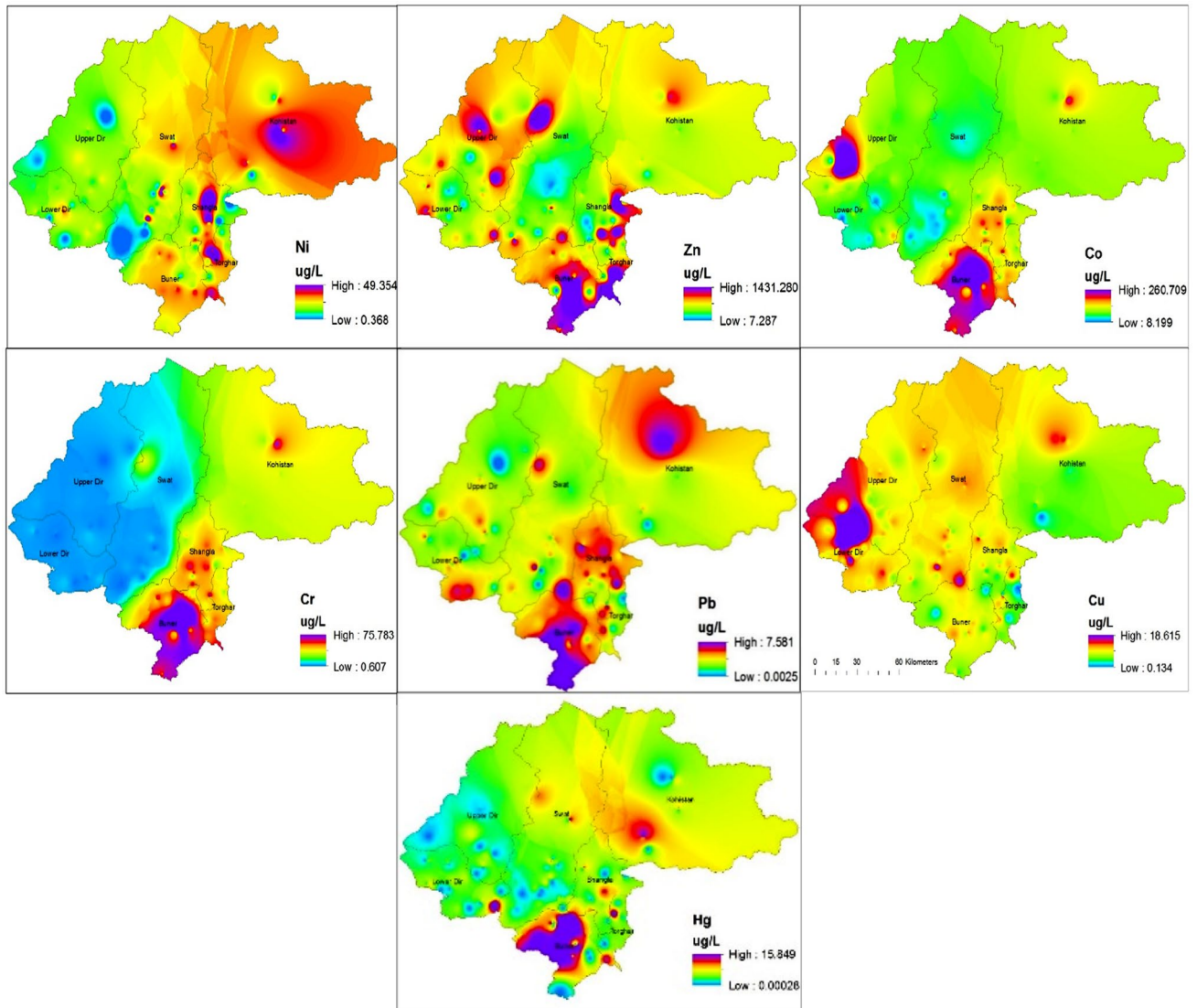


Fig. 4 Spatial distribution of selected PTEs in all schemes of the study area

values of PTEs were found to be in order of $Zn > Pb > Cu > Cr > Co > Ni > Hg$, and $Cu > Zn > Pb > Cr > Co > Ni > Hg$, and $Zn > Cu > Cr > Pb > Co > Ni > Hg$, for NGOs, GOV and SBS, respectively.

The mean concentrations of *E. coli* were 2.18, 1.80 and 2.00 MPN/100 mL in SBS, NGOs and GOV, respectively. The percentage contribution of *E. coli* to waterborne diseases are presented in Table 1, and Fig. 5a, b). The *E. coli* concentration was observed only in 19% of the water samples ($n=23$) out of 120 samples, in which 10% of *E. coli* was detected in SBS, 5% in GOV and 4% in NGOs schemes. In SBS scheme, the maximum concentration of *E. coli* was 6 MPN/100 mL, and minimum 1 MPN/100 mL was detected in the Torghar and Kohistan districts. For the NGOs scheme, the high concentration of *E. coli* was 2 MPN/100 mL, in the Lower Dir district, and lower 1 MPN/100 mL, was

detected in the Buner district. Furthermore, the highest *E. coli* value (5 MPN/100 mL) was observed in water samples of the Buner district, while the lowest concentration (1 MPN/100 mL) was detected in the Upper Dir on GOV scheme water samples. *E. coli* values were above the acceptable limits of Pak-EPA (2008), USEPA (2011) and WHO (2011). In study area, *E. coli* contamination in all schemes were found to be in decreasing order $SBS > GOV > NGOs$. In comparison, the present study had concentration of *E. coli* colony that was higher than those reported by (Khan et al. 2013b), and also lower than the previous study of *E. coli* contamination in drinking water samples in Karachi, Pakistan conducted by (Ahmed et al. 2020), and in drinking water resources of Swat, Pakistan (Khan et al. 2018). The presence of *E. coli* contamination in the aforementioned districts may have potential risk to local inhabitants of the

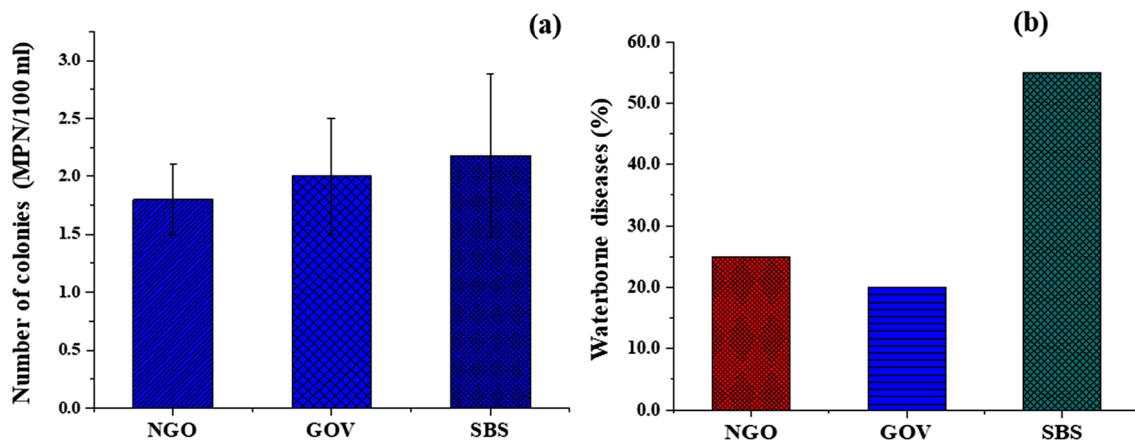


Fig. 5 Contamination level of **a** *E. coli*, and **b** percentage of waterborne diseases in all schemes

study area with regards to their drinking water sources. For instance, pathogenic strains of *E. coli* bacteria are highly hazardous for human health (Mara et al. 2009), and can cause serious gastrointestinal diseases (hepatitis and typhoid fever) in humans (Ahmed et al. 2020). *E. coli* contamination in the present study reflects the improper discharge of organic wastes and continuous seepage from septic tanks. Furthermore, the *E. coli* had low-moderate contamination in the study area schemes, but drinking water sources should be completely free from pathogenic *E. coli* bacteria, and other pathogens in order to be suitable as drinking water for public consumption, as reported by Pak-EPA (2008). Furthermore, the presence of *E. coli* in drinking water and its contamination could be associated with human or warm-blooded animals and the possible occurrence of pathogenic organisms. These pathogens when present in waste or contaminated water source cause diseases and most common illness like diarrhea (Jafari et al. 2012).

Pollution Identification Degree of PTEs and *E. coli*

The PLI, CF, and WPI of all PTEs in drinking water sources for all schemes were determined in the study area, and are presented in Table 3. The CF values of studied PTEs showed low to high contamination level for all schemes. The high CF values were 1.58, 11.3, and 2.33, 1.68, 15.3, and 3.72, and 4.15, 23.6, and 5.49 for Hg, Zn, and Co for NGOs, GOV, and SBS, respectively. Although low CF values were observed for Cu (0.13, 0.16, 0.12), Cr (0.01, 0.06, 0.13), Ni (0.32, 0.37, 0.44), and Pb (0.15, 0.17, 0.24) for NGOs, GOV, and SBS, respectively. The CF values for Cu, Cr, Ni, and Pb were all < 1, which indicates low contamination level. The CF were high (CF > 1) for Hg, Zn, and Co, indicating moderate water contamination level in all the studied schemes of the study area, when compared with background level. High concentration of

Table 3 Contamination factor (CF), pollution load index (PLI) and water pollution index (WPI) values for selected parameters in studied schemes

Parameters	NGOs	GOV	SBS
CF			
Cu	0.13	0.16	0.12
Cr	0.01	0.06	0.13
Hg	1.58	1.68	4.15
Zn	11.3	15.3	23.6
Ni	0.32	0.37	0.44
Co	2.33	3.72	5.49
Pb	0.15	0.17	0.24
<i>E. coli</i>	0.46	0.51	0.56
pH	1.10	1.10	1.12
TDS	0.03	0.04	0.08
EC	0.001	0.03	0.06
NO ₃	2.05	2.34	2.46
Turbidity	0.75	0.75	1
PLI	0.014	0.007	0.012
WPI	0.94	0.97	0.99

Hg, Zn, and Co and their high CF values in all schemes could be associated with runoff from agricultural lands, industries and domestic waste (Abdullah et al. 2011).

The PLI values of all schemes in the study area were < 1, indicating significantly low contamination in the study area especially the northern districts. The WPI values of all the studied parameters were 0.94, 0.97, and 0.99 for NGOs, GOV, and SBS, respectively (Table 3). The WPI values were found to be < 1, indicating a moderate contamination of drinking water sources for all schemes. Based on the results obtained for WPI, it can be inferred that drinking water sources of all schemes are low to

moderately polluted, may pose some risks to human health and cause potential health problems in the study area.

Source Apportionment of Parameters

Principal component analysis multilinear regression (PCA–MLR) was applied for pollution source identification and percentage contribution of selected parameters in drinking water sources of NGOs, GOV, and SBS. PCA is a very effective technique used for qualitative evaluation, variability and correlation of water variables (Iranmanesh et al. 2014). Therefore, the PCA results are presented in Table S1. Overall, six significant loading factors with eigenvalues greater than 1 were obtained for all the water parameters. The six factors of the NGO, GOV, and SBS water sources described 79.84%, 76.41%, and 79.99% of total variations with eigenvalues of 10.5, 10.1, and 10.5, respectively (Table S1).

Factor 1 (F1) showed high positive loadings of TDS ($r=0.80$), EC ($r=0.79$), Cr ($r=0.81$), Co ($r=0.63$), and Pb ($r=0.66$), with a total variance of 25.8%, with an eigenvalue of 3.36 in NGOs scheme. For GOV scheme, F1 is dominated by TDS ($r=0.61$), EC ($r=0.61$), Cr ($r=0.83$), Hg ($r=0.65$), and Co ($r=0.70$) with a total variance of 21.2%, with an eigenvalue of 2.77. For SBS scheme, F1 is predominantly influenced by negative loadings of TDS ($r=-0.61$), and EC ($r=-0.63$), and high positive loadings of Cr ($r=0.74$), and Co ($r=0.74$) with a total variance of 18.9%, with an eigenvalue of 2.46. These results showed that F1 had moderate-high loadings of physicochemical and PTEs contribution, suggesting that anthropogenic sources were the origins of the studied toxic elements in the drinking water sources. Some of these anthropogenic sources include pollutants associated with agricultural practices, such as use of pesticides, fertilizers, fertilizer, and other agricultural practices, as well as domestic waste disposal (Grigg et al. 2018). Thus, F1 is assumed to show anthropogenic sources of contaminants in the study area.

Factor 2 (F2) exhibit high loadings of pH ($r=0.78$), Cu ($r=0.66$), and Co ($r=-0.60$), with total variance of 17.0%, and eigenvalue 2.21 in NGOs scheme as presented in Table S1. For GOV scheme, F2 had moderate loadings of TDS ($r=-0.69$), EC ($r=-0.69$), and Co ($r=0.51$) with a total variance of 15.9%, with an eigenvalue of 2.07. While, F2 had also moderate loadings of TDS ($r=0.61$), EC ($r=0.58$), Cu ($r=-0.65$), and Ni ($r=0.52$) in SBS with a total variance of 16.2%, with an eigenvalue of 2.11. PTEs such as Cu, Co, and Ni in F2 could be accumulated to the waterbodies and food chain that might be originated from agricultural activities. Factor 3 (F3) recorded high amounts of Turbidity ($r=0.73$), NO_3 ($r=-0.52$), and *E. coli* ($r=0.55$), with a total variance of 11.9% and eigenvalue of 1.55 in NGOs scheme. F3 had Pb loading ($r=0.72$) in GOV

scheme, and low loadings of *E. coli* ($r=-0.58$) and Pb ($r=0.76$) in SBS scheme with a total variance of 13.0% and 15.2%, with eigenvalues of 1.70 and 1.98, respectively. Thus, F12 and F3 could be attributed to anthropogenic sources in the study area. While, F4 showed moderate loadings of NO_3 ($r=0.61$), Hg ($r=-0.50$) in NGOs, and Turbidity ($r=0.61$), and Cu ($r=-0.52$) in GOV, and Turbidity ($r=0.73$), NO_3 ($r=0.61$), and Hg ($r=0.55$) in SBS with a total variance of 9.64%, 11.0% and 12.1% with eigenvalues of 1.25, 1.44 and 1.58, respectively. F5 and F6 had negative loading of Zn ($r=-0.50$) in NGOs, *E. coli* ($r=0.70$) in GOV, and pH ($r=0.57$), and NO_3 ($r=0.54$) in SBS with a total variance of 9.08%, 8.58% and 10.1% with eigenvalues of 1.18, 1.12, and 1.32, respectively. Whereas F6 exhibit negative loading of Hg ($r=-0.52$) in NGOs, pH ($r=0.59$), and Cu ($r=-0.50$) in GOV, and Zn ($r=0.67$) in SBS with a total variance of 6.31%, 6.52% and 7.27% with eigenvalues of 1.00, 1.01, and 1.05, respectively. This demonstrates that F5 and F6 had low contributions to the PCA (<20%), as compared to F1, F2, F3 and F4. Furthermore, TDS loadings in all the factors could be associated to the geogenic sources such as leaching from mafic, felsic and carbonated rocks that exist in the northern parts of the districts. While, the sources of NO_3 could be attributed to regional sulfide-rich soil as well as the use of agrochemicals, as previously reported by (Gul et al. 2015), indicating both the natural and anthropogenic origins within the study areas. In addition, the *E. coli* contamination are possibly related to various anthropogenic activities including improper disposal of animal wastes in open fields, and leakage from septic tanks in residential areas (Khan et al. 2013b). Therefore, F4, F5 and F6 represent both the geogenic and anthropogenic sources.

Health Risk Assessment

The health risk to humans, using ADI and HQ values, was computed for adults and children in the studied schemes as shown in Table 4. Zn had the highest ADI value (7.30), among the PTEs, while Cu had the lowest ADI value ($9.08\text{E}-02$) for children in NGOs scheme. Similarly, Zn showed high ADI value of ($6.63\text{E}+00$), and Cu had low ADI value ($8.25\text{E}-02$) for adults in NGOs schemes. The HQ results showed that all the values of HQ for PTEs were less than 1 for both adults and children, except Hg and Co values of HQ were found (> 1) in Kohistan district for both adults and children in NGOs scheme, whereas the HQ results for drinking water sources were found in the safe limits ($\text{HQ} < 1$) in all the districts. The HRI for all the studied PTEs were observed to be in decreasing order $\text{Co} > \text{Hg} > \text{Ni} > \text{Zn} > \text{Cu} > \text{Pb} > \text{Cr}$ for both the adults and children in NGOs scheme.

Similarly, the highest ADI values were observed for Zn (8.98), and the lowest ADI values for Pb ($5.75\text{E}-02$) in

Table 4 ADI and HQ values of PTEs for adults and children in water supply schemes of the study area

Schemes	PTEs	ADI adults	ADI children	RFD	HQ adults	HQ children
NGOs	Cu	8.25E-02	9.08E-02	37.0	2.23E-03	2.45E-03
	Cr	3.31E-02	3.64E-02	1500	2.20E-05	2.43E-05
	Hg	4.39E-02	4.83E-02	0.003	1.46E+01	1.61E+01
	Zn	6.63E+00	7.30E+00	300	2.21E-02	2.43E-02
	Ni	3.49E-01	3.84E-01	20.0	1.74E-02	1.92E-02
	Co	5.14E-01	5.65E-01	0.02	2.57E+01	2.83E+01
	Pb	2.47E-02	2.72E-02	36.0	6.87E-04	7.56E-04
GOV	Cu	9.83E-02	1.08E-01	37.0	2.66E-03	2.93E-03
	Cr	1.43E-01	1.57E-01	1500	9.50E-05	1.05E-04
	Hg	4.67E-02	5.14E-02	0.003	1.56E+01	1.71E+01
	Zn	8.98E+00	9.89E+00	300	2.99E-02	3.30E-02
	Ni	4.05E-01	4.46E-01	20.0	2.03E-02	2.23E-02
	Co	8.17E-01	8.99E-01	0.02	4.08E+01	4.50E+01
	Pb	5.22E-02	5.75E-02	36.0	1.45E-03	1.60E-03
SBS	Cu	7.56E-02	8.32E-02	37.0	2.04E-03	2.25E-03
	Cr	3.37E-01	3.71E-01	1500	2.24E-04	2.47E-04
	Hg	1.15E-01	1.27E-01	0.003	3.84E+01	4.23E+01
	Zn	1.38E+01	1.52E+01	300	4.61E-02	5.07E-02
	Ni	4.72E-01	5.20E-01	20.0	2.36E-02	2.60E-02
	Co	1.21E+00	1.33E+00	0.02	6.03E+01	6.64E+01
	Pb	7.50E-02	8.26E-02	36.0	2.08E-03	2.29E-03

GOV scheme for both the adults and children, in the study area. HQ values were also high ($HQ < 1$) for Hg and Co in GOV scheme, demonstrating that a high contamination level occurred in the Buner district, in comparison with other districts. The HQ results for all the selected PTEs were observed to be in decreasing order of $Co > Hg > Ni > Zn > Cu > Pb > Cr$ for both the adults and children in GOV scheme. For SBS scheme, similar results were recorded for ADI values of selected PTEs in the study area. ADI had high values for Zn ($1.38E+01$), and Co ($1.21E+00$) in SBS scheme, while the lowest value was observed for Cu ($9.756E-02$) for adults. The high ADI value of Co observed was ($1.33E+00$), whereas the lowest value was observed for Cu ($8.32E-02$) for children in SBS scheme. The maximum and minimum ADI and HQ values for PTEs (Co and Cu) were observed in the Kohistan and Torghan districts in comparison with other districts. Overall, the ADI and HQ results for the children were relatively higher than that for the adults in all the studied schemes. HQ values of Co and Hg showed a high potential health risk ($HQ < 1$) in all (NGOs, GOV, and SBS) schemes. The HQ for all the PTEs were found to be in decreasing order $Co > Hg > Ni > Zn > Cu > Pb > Cr$ in SBS scheme for both the adults and children. The ADI and HQ values were lower than the health risk study of selected PTEs except (Hg and Co), as reported by (Nawab et al. 2015, 2016).

Questionnaire Survey

Different types of common illnesses and adverse waterborne diseases symptoms such as diarrhea, dysentery, hepatitis A, B, and C, nausea, kidney and skin problems were generally reported by the local inhabitants during the questionnaire survey in the study area. Our survey revealed that the study area has maximum *E. coli* contamination in SBS scheme of the Swat, Torghan, and Kohistan districts, and could be associated with animal waste disposal, poor sewage system, and solid waste disposal resulting to aforementioned diseases. For instance, lack of toilet and direct disposal of sewage could pollute the water sources causing human exposure to fecal-oral cycle pathogens in Kohistan and Torghan districts. *E. coli* contamination in water sources may lead to various diseases like intestinal infections, stomach problem, typhoid, diarrhea, cholera, and other adverse diseases (Emmanuel et al. 2009). High incidences and occurrence of such waterborne diseases have been previously reported in rural areas of Pakistan (Daud et al. 2017). Similarly, the *E. coli* contamination was observed in drinking water sources of districts Swat, Upper Dir and Buner in GOV scheme. The major sources could be associated to poor water pipeline system and domestic sewage discharge in the regions. While for NGOs scheme, the Lower and Buner districts have weak and rusted water pipelines, as well as birds and animal

feces in open wells in public places, indicating a major contribution to *E. coli* contamination.

In the hilly northern regions of the study area, females are generally responsible for bringing water from various (10–20 years old) water supply schemes which are vulnerable to various waterborne diseases like diarrhea, vomiting, dysentery, hepatitis and typhoid fever etc. While *E. coli* contamination were also found in water sources of different schemes (NGOs, GOV, and SBS), resulting from animal/bird feces, toilets, domestic effluents and sewerage leakages into the concerned water sources and schemes. It was observed that there was no standard distance, and toilets were within a 30-m radius to the water sources schemes. The study showed that 27% were closed in SBS, 12% and 17% in NGOs and GOV schemes, respectively. The presence of human excreta in drinking water sources can demonstrates the existence of coliform bacteria directly and indirectly (Laluraj et al. 2006). In the study area, contaminated drinking water in all schemes contributed to spread diarrhea (48%, 33% and 27%), while dysentery and stomach problems (25%, 21%, and 18%) and (14%, 12%, and 18%) following in the order of SBS > GOV > NGOs respectively as presented in Table 5. Although age wise, children were apparently more effected from diarrhea, while adults and old age people had stomach problems. The diarrhea and stomach problems were found in age-wise category in the order of adult > old age people > children, and children > adults > old age people, respectively. This could be as a reason of weak immune system of old age people, and poor sanitation system in the regions. Although diarrhea is prominent reason of children deaths along with adverse health effects on child growth (Pruss-Ustun & Organization 2008). In addition, other pathogenic infectious diseases like intestinal infections, typhoid fever, stomach problem, and cholera could occur due to coliform bacteria (Emmanuel et al. 2009).

Conclusions

The present study concluded that physicochemical had less effect on drinking water quality due to their low and moderate contamination level in all schemes. The PTEs such as Zn distributed with high concentration level, followed by Co. While, Hg had low concentration level

among other PTEs in NGOs, GOV, and SBS. Mean values of PTEs were found in decreasing order of; Zn > Co > Ni > Cr > Cu > Pb > Hg in all schemes (NGOs, GOV, and SBS) of the study area. Elevated Hg and Cr concentrations was found in SBS, whereas Co were found to be high in GOV and SBS. As a result, exceeded the standard limits of WHO and Pak-EPA than the other PTEs in the study area. Health risk of PTEs showed no potential risk (< 1), except Co and Hg had the high health risk in GOV, and SBS for both the adults and children. Although the questionnaire survey showed that microbial contaminated water sources of hand pumps, open wells and taps water of the Swat, Torghar, Kohistan, Upper Dir, and Buner districts were highly most probably due to poor pipelines system, and domestic sewage discharge in GOV and SBS. The PCA results showed that contamination of the studied parameters was associated to high anthropogenic sources of agriculture practices and less contribution of geogenic sources. *E. coli* contamination was primarily related to animal wastes disposal as well as poor sanitation system of septic tanks seepage in Northern residential areas. Overall, the results showed that PTEs and *E. coli* contamination were high in SBS in comparison with GOV, and NGOs schemes. In addition, local inhabitants of aged people are likely to be affected more than the adults and children, due to their weak immune system. Hence, children would suffer more from diarrhea, while adults and aged people would have stomach problems, resulted from *E. coli* contaminated water consumption. In order to cope with such microbial contamination, it is necessary to introduce and develop noncorrosive and good quality water supply pipes with proper depth, in the above districts of GOV and SBS schemes. It is highly recommended that to overcome and abate the pollution sources by proper water treatment and improvements in distribution of water sources across the whole northern districts, should be implemented following WHO and EPA guidelines on regional basis to provide clean drinking water for public.

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Table 5 Percentage (%) wise values of various diseases and age-wise distribution in all schemes of the study area

Disease	SBS	GOV	NGOs	Children	Adults	Old age people
Diarrhea	48	33	27	60	40	18
Dysentery	25	21	18	55	30	20
Stomach problem	14	12	18	25	70	40

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Declarations

Competing interest The authors declare that they have no known competing interest.

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