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ORIGINAL ARTICLE

Groundwater quality assessment and human health risks in Gujranwala District, Pakistan

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Abstract

The availability of safe drinking water is imperative for healthy life but access to safe drinking water has become a major problem around the world, especially in developing countries such as Pakistan. The present study aimed to: assess the suitability of groundwater for potable use in Gujranwala district, Pakistan; examine the spatial distribution patterns of water quality parameters; and to identify the prevalence of waterborne diseases among locals and health risks to humans due to the consumption of groundwater. Eighty drinking water samples were collected from different areas of Gujranwala and analyzed following Standard American Public Health Association methods. A questionnaire survey related to the incidence of waterborne diseases in the area was also carried out. The averaged water quality index (AWQI) was computed using ArcGIS 10.3 model builder. The AWQI map indicated that the water quality was generally suitable for potable use with regard to its physiochemical parameters. However, 97.5% water samples were found to be bacteriologically contaminated. The mean concentration of metals in drinking water showed a decreasing trend in the order Cr > Cu > Zn > As > Co > Ni > Cd. Health risk index (HRI) was also calculated for exposure to metal concentration. For Cd, one sample showed an HRI value > 1 i.e. 1.59 and 1.36 for child and adult, respectively, while HRI for As showed values > 1 varying between 0.5 and 11 for child, and 0.4 and 9.6 for adults. For other metals HRIs was less than 1 (considered to be safe for the consumers). The study concludes that groundwater quality of study areas of Gujranwala has mostly deteriorated.

Keywords Fecal contamination · Waterborne diseases · Heavy metals · Physicochemical parameters · HRI · Spatial distribution patterns

Introduction

Communities throughout the world generally prefer to use groundwater as a source of drinking water because this source is generally free from contamination. However, due to rapid population growth and anthropogenic activities, contamination of groundwater as well as surface water bodies is increasing, especially in developing countries (Afzal et al. 2000; Shahid et al. 2015; Tariq et al. 2007).

According to a World Health Organization/United Nations International Children's Emergency Fund (WHO/UNICEF) report published in 2017, 844 million people around the world do not have access to basic drinking water services. Thus, the vulnerability of populations to diseases has increased with increased exposure to contaminated water. This situation is of most concern in developing regions in Africa and Asia, where water quality is deteriorating due to rapid urbanization, land degradation, industrialization, deforestation, unhygienic conditions and poor sanitation and waste management practices. According to an estimate, 20% of the population in eight countries of sub-Saharan Africa uses limited drinking water services (WHO/UNICEF 2017). Similarly, 669 million people in Asia still do not even have access to safe drinking water sources (WHO/UNDP/ADB/UNESCAP 2006).

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According to the Federal Flood Commission, the per-capita water availability is following a decreasing trend (1310 m^3 year in 2005–865 m^3 year 2018). This trend in water vulnerability is due to increased variability in river flows attributed to glaciers' retreat, depletion of water storage capacity, riverine floods, and droughts, change in frequency and intensification of extreme climate events (Business Recorder 2018: Siegmann and Shezad 2005). Pakistan, once a water-rich country, has now become water stressed and is ranked 80th in the world as regards the availability of safe and clean water. About 75% of population does not have sustainable access to safe drinking water which contributes to 30% of communicable diseases and 40% of the deaths in the country. Reportedly, thousands of children in Pakistan succumb to death every year from otherwise preventable diseases. Insufficient intake of essential nutrients and shortage of clean water poses innumerable impacts on children's health. Accordingly the current status of water quality has led to significant public costs, such as premature deaths, infant deaths, economic and financial costs due to diseases attributable to poor sanitation, environmental costs, and other welfare costs (Mehmood et al. 2013; Murtaza et al. 2015; The Nation 2017; Zahid 2017).

The Punjab Province in Pakistan, with an estimated 101.4 million people, accounts for approximately 55.6% of the total country's population. Punjab has a regulatory framework for managing drinking water quality and the province is required to implement policies and regulations to limit the effects of groundwater pollution on public health. Historical data showed that the water quality in Punjab is generally suitable for potable and irrigation use. However, over the last 30 years there has been an increasing trend of waterborne diseases such as diarrhea (Afzal et al. 2000; Tahir et al. 2010).

In 2012, Public Health Engineering Department (PHED), in collaboration with UNICEF, conducted a comprehensive study on water quality of Punjab. A total of 46,000 samples were collected from 23,000 different rural areas of districts in Punjab. The results showed that almost 36.3% villagers consume chemically contaminated water and 32.7% villagers drink bacteriologically unfit water which means that about "third of all villages" in Punjab intake unhealthy water. Most adverse results were reported from Gujranwala, Lodhran and Sahiwal where over 60% water samples failed to comply chemically and over 80% water samples from Gujrat, Gujranwala and Narowal showed excessive fecal contamination. According to Daud et al. (2017) the major reason is the disposal of industrial effluents in surface water bodies whereby the inorganic contaminants enter into groundwater sources. Moreover, septic tank leakages, open sewerages, abandoned boreholes and eroded drinking water pipes also caused fecal contamination of drinking water sources.

The overall bacteriological and chemical status of water quality in Punjab identified Gujranwala, Gujrat, Narowal, Lodhran and Sahiwal as the most affected districts (Punjab Sector Development Plan 2014). In a very recent study by Akhtar et al. (2019), 71% water supply schemes in Mianwali were found to be bacteriologically unfit and polluted with fecal coliform bacteria, thereby posing risk to human health. Consequently, monitoring of drinking water quality on regular basis is important in these areas because ingestion of contaminated water results in various structural and functional effects, infectious diarrhea, vomiting, stomach pain, dysentery, cholera, enteric fever, cytotoxicity, mutagenicity and carcinogenicity etc. (Bain et al. 2014).

Consequently, the current study was carried out to assess the present status of water quality of selected areas of Gujranwala and to determine the spatial distribution patterns of water quality parameters. The present study aimed to: (1) assess the quality of groundwater which provides all of the water used by the local population for drinking purpose; (2) examine the spatial distribution patterns of water quality parameters for selected urbanized areas of Gujranwala; and (3) recommend safety measures to ensure that water sources remain suitable for human consumption since last two decades is the major objective of the study. This study also examined the relationship between microbiological contamination of water sources and the incidences of waterborne diseases due to the consumption of groundwater by local communities.

Description of the study area

The study area included urbanized areas of selected tehsils, local administrative divisions, of Gujranwala district (Gujranwala and Kāmoke Tehsil) which are a mixture of agricultural zones and urban/industrial areas. These areas are prime urban corridors and a hub of economic activities. Gujranwala is situated in the (upper) *Rechna Doab* (area between the Chenab and Ravi rivers) which can be categorized as being a semi-arid region. Large differences in precipitation exist between northern and southern regions of Doab with the rate of precipitation decreasing in a southward direction (Jehangir et al. 2002).

According to a USGS (United States Geological Survey 1967) report, test holes drilled to a maximum depth of about 1500 feet revealed that Precambrian basement rocks are overlain directly by Quaternary alluvium (Greenman et al. 1967; Rehman 1997). The alluvium deposits at upper Doab area are composed of silty clays/clayey silts and fine to medium sands. By contrast, coarse sand with localized clay lenses is present in lower Doab area (Rehman 1997). These sediments are highly permeable (Khan et al. 2003) and form an unconfined aquifer which has a much greater lateral permeability than a vertical permeability (Mundorff et al. 1976).

It is noted that there are no groundwater regulations in the Punjab Province to prevent the digging of boreholes for extraction of ground water for human consumption and irrigation purposes. Unfortunately, due to weak laws, the digging of boreholes for household consumption is carried out by private contractors who are not qualified and trained to take effective measures to avoid contamination of aquifer during digging of wells. These private contractors mostly used conventional methods of digging boreholes and using borehole machines only to extract water from 300 to 600 feet. These groundwater extraction pumps are not registered by any government agencies to control the exploitation of over pumping and contamination of groundwater. The authors contacted relevant authorities regarding “Groundwater Regulatory Frame Work” but were informed that some documents were submitted, many years back, to relevant authorities for approval but till date they were not granted approval.

Figure 1 illustrates the location of the study area and sampling points in Gujranwala District.

Materials and methods

To analyze the drinking water quality, 80 groundwater samples were collected from different sources including from motor driven pumps, hand pumps, filter plants and community taps (borehole depth: 15.24–182.88 m deep). Samples were collected, stored and preserved under aseptic conditions according to the standard procedures of American Public Health Association (APHA) Method 1060 (Rice et al. 2017). Table 1 lists the parameters analyzed along with relevant APHA reference methods and the techniques used.

To determine consumer’s perception and prevailing health impacts on public, a questionnaire survey (regarding drinking water, sanitation and hygienic conditions) was conducted among the residents of 80 households.

Moreover, a health risk assessment (HRI) was carried out by calculating the chronic daily intake (CDIs) and health risk indexes (HRIs) for heavy metals in drinking water using the formula as follows

$$\mathrm{CDI} = (M_\mathrm{c} \times L_\mathrm{w})/W_\mathrm{b},$$

where, M_c = concentration of metal in water (mg/L), while L_w (L/day) is daily water intake which is taken as 1 L/day for child and 2 L/day for an adult (USEPA 2011) and W_b (kg) is average body weight which was based on information from the respondents of study area as 29.5 kg and 69 kg for child and adult, respectively.

$$\mathrm{HRI} = \mathrm{CDI}/\mathrm{RfD}$$

where Rfd reference dose for oral toxicity the metal; According to USEPA IRIS (Integrated Risk Information System), the Rfd for As is 0.0003 mg/kg/day and for Cd it is 0.0005 mg/kg/day (www.epa.gov/iris, 2018)

Spatial distribution patterns of various parameters that exceeded the permissible limits of the WHO drinking water guidelines and PS was analyzed through Kriging/Co-kriging technique from ArcMap 10.1 software which was used for unbiased prediction. Moreover, this technique provides minimum variance and interpolation error that helps to create better estimation. A Gaussian model was used for all parameters which are best fitted model for drinking water quality prediction that uses the average reading to make smooth line on graph. Gharbia et al. (2016) also identified Kriging/Co-kriging the best method for predicting the spatial variability of various groundwater quality parameters. Karami et al. (2018) also supported Gharbia by considering Kriging as most accurate method for interpolating groundwater quality parameters.

Results

The results of analysis of physical parameters of drinking water are summarized in Table 2. The descriptive statistical results of various groundwater quality parameters are provided in Table 3. Table 4 gives the maximum and minimum values of HRI calculated for samples exceeding standard limits of Ar and Cd. Table 5 provides a summary of the results of questionnaire survey

Spatial distribution patterns

Spatial variation of various parameters that exceed from permissible limit of WHO standards and PS are shown in Figs. 2, 3, 4, 5 and 6:

Discussion

Eighty groundwater samples were analyzed for physiochemical and bacterial analysis. Of these, only 2 (2.5%) of the samples met the drinking water criteria while bacterial contamination was found in 78 (97.5%) of the samples (fecal contamination with colony count ranging from 0 CFU to > 300 CFU or too numerous to count). Samples with satisfactory results were obtained only from Water and Sanitation Agency (WASA) plants (at 182.88 m depth) that showed that groundwater from deeper aquifers are safer for human consumption. Some nearby houses collect water from these plant taps for drinking purpose while others consume water from their own borehole pumps. The community boreholes showed high fecal loads, especially for boreholes that

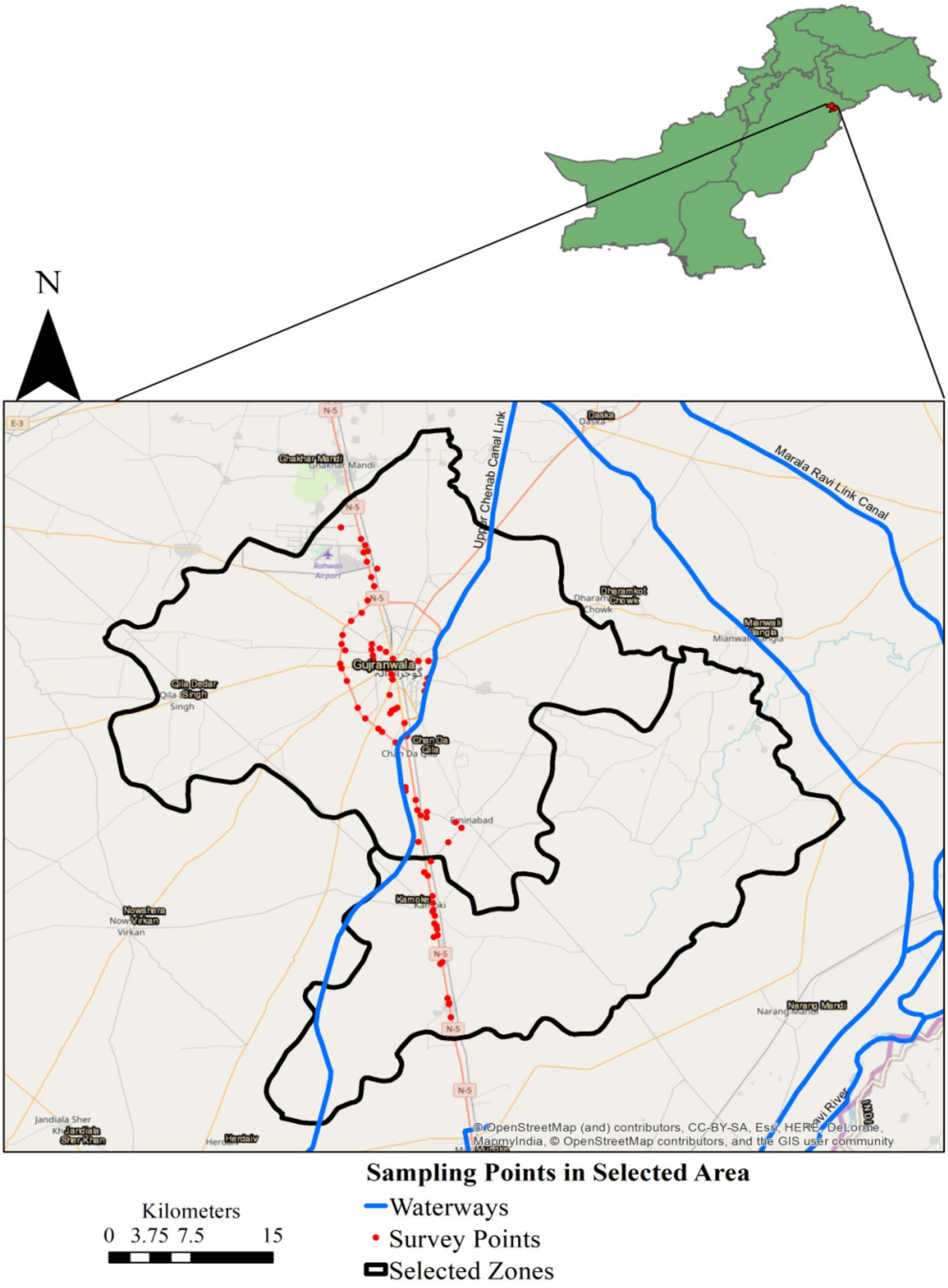

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Fig. 1 Map of selected zones and sampling points in study area

access the upper part of the unconfined aquifer (most wells are about 36.57 m deep) because of open municipal waste dumping and the presence of cow dung in the proximity of groundwater sources. Moreover, septic tank leakages, open sewerages, poor and substandard borehole construction, abandoned boreholes and cross connections of eroded

Table 1 Analytical Techniques for selected parameters and reference methods

Sr. no.	Parameters	Technique/method	Instrument manufacturers and model no.	Reference methods
1	pH	pH-meter	JENWAY 3510	APHA 4500 H^+
2	EC	Conductivity meter	JENWAY 4510	APHA 2510
3	TDS	Electrometric	JENWAY 4510	2540 D
4	Turbidity	Nephelometric	HI93703, HANNA Italy	2130 B
5	Total Hardness	Titrimetric method	–	2340 C
6	Total Alkalinity			2320 B
7	Na^+	Flame photometry	JENWAY PFP 7	3500-Na (B)
8	K^+			3500-K (B)
9	SO_4^{2-}	Spectrophotometry	CECIL CE 4002	4500-SO_4^{2-} (E)
10	Ca^{2+}	Titrimetric method	–	3500-Ca (B)
11	Mg^{2+}		–	3500-Mg (B)
12	Cl^-		–	4500-Cl^- (B)
13	DO	DO meter	JENWAY 970, UK	4500-O (G)
14	Temperature	pH meter	JENWAY 3510	APHA 2550- B
15	Heavy Metals (Cd, Cu, Co, Zn, Ni, Cr)	Atomic absorption spectrophotometry	Buck scientific 210 VGP, USA	3110 (Instrument operating manual)
16	As	Kit method	MERCK Arsenic Kit	–
17	Thermo tolerant bacteria	Membrane filtration technique	*Autoclave* (SANYO Japan MLS-2420 U) *Laminar flow cabinet* (Varioline Intercool Pakistan SVC 750) *Incubator* (Fisher Scientific, USA/252D)	APHA 9222-B

sewerage and water pipelines increase the risk of fecal load contamination in drinking water sources (rendering water unfit for drinking).

According to overall results of the questionnaire survey, respondents claimed that they visited physician occasionally within the last year due to diarrhea/stomach ailment, nausea, vomiting and gastroenteritis. The waterborne diseases are more prominent during the summer season when the mean temperature is about 33–37 °C. The interviews with people in the age-group of 60–75 years revealed that the water quality 40 years ago was much better than it currently is and public health data from the Gujranwala district also showed a lower number of reported gastroenteritis cases than is currently the case. People of this age-group indicated that drinking-water quality had deteriorated with the passage of time due to the rapid unplanned and unsystematic growth of small- and medium-sized industrial enterprises (SME) that have been established in Gujranwala.

There are now more than 2000 SMEs (including steel, textile, leather, plastic waste and food-based industries) that are scattered throughout Gujranwala. During discussions, respondents correlated these diseases to stagnant industrial/municipal waste water at different location in Gujranwala which ultimately contaminated the groundwater. The questionnaire respondents suggested that contamination of drinking water in their boreholes was due to contamination by stagnant wastewater in their area, abandoned boreholes and poor municipal solid waste disposal practices. Poor sewerage system infrastructure and large number of sewerage water leakages were also reported by the community. Moreover, sewage and drinking water supply pipes were laid down side by side due to which contaminated sewage water gets mixed with drinking water when the community uses water suction pumps. These sources of water contamination have also been reported elsewhere (Kazmi et al. 2015; Khan et al. 2013).

The results of the questionnaire pointed out that most of the people have no other option than to drink water from their own borehole pumps because municipal water supply from deep wells is not available at all times. This situation is similar to many other cities in Pakistan such as Gujrat, Jhelum, Multan, Muzafar garh and Sukkar where mostly drinking water samples have shown bacteriological contamination due to poor sewerage systems, combined with the effects of well-drained soils and abundant boreholes (Alamgir et al. 2017; Khan et al. 2017; Shar et al. 2010; Tariq et al. 2004).

The questionnaire revealed that more than 90% households with water storage tanks do not regularly and properly decontaminate/wash the storage tanks. Additionally, field observations of a number of tanks indicated that they contained green algae and accumulated dirt. Therefore, these water storage tanks could be a source of bacterial contamination in drinking water used by local households. Lack of regular maintenance and cleaning of storage tanks may result in bacteriological contamination (Antony and Renuga

Table 2 Results of Physical Parameters analysis

Sample code	Color	Odor	Taste	Turbidity (NTU)	TSS (mg/L)	Temperature (°C)
S1	Light yellow	Odorless	Tasteless	0.64	170	23.2
S2	Pale yellow	Odorless	Tasteless	0.11	30	23.3
S3	Colorless	Odorless	Tasteless	0.93	230	23.3
S4	Colorless	Odorless	Tasteless	0.00	0	23.3
S5	Colorless	Odorless	Tasteless	1.94	220	23.3
S6	Pale yellow	Odorless	Tasteless	0.26	10	23.2
S7	Colorless	Odorless	Tasteless	0.00	0	23.4
S8	Colorless	Odorless	Tasteless	0.17	40	23.2
S9	Colorless	Odorless	Tasteless	0.17	60	23.4
S10	Colorless	Odorless	Tasteless	0.22	60	23.2
S11	Colorless	Odorless	Tasteless	0.30	210	23.2
S12	Rusty yellow	Odorless	Tasteless	1.28	200	23.3
S13	Colorless	Odorless	Tasteless	0.00	0	23.3
S14	Colorless	Smelly	Tasteless	0.19	20	23.3
S15	Colorless	Odorless	Tasteless	0.19	30	23.3
S16	Pale yellow	Odorless	Tasteless	0.47	40	23.2
S17	Pale yellow	Odorless	Tasteless	1.26	230	23.3
S18	Pale yellow	Sewage-like odor	Tasteless	0.09	0	23.2
S19	Rusty yellow	Odorless	Tasteless	1.46	50	23.3
S20	Colorless	Odorless	Tasteless	0.02	0	23.3
S21	Colorless	Odorless	Tasteless	0.33	40	23.3
S22	Colorless	Odorless	Tasteless	0.00	0	23.3
S23	Colorless	Odorless	Tasteless	0.82	210	23.3
S24	Colorless	Odorless	Tasteless	0.34	240	23.0
S25	Colorless	Odorless	Highly Salty	0.01	0	23.2
S26	Colorless	Sewage-like odor	Tasteless	0.32	30	18.9
S27	Colorless	Odorless	Tasteless	0.05	0	18.9
S28	Colorless	Odorless	Salty	0.40	50	18.9
S29	Colorless	Odorless	Slightly salty	0.85	70	18.9
S30	Colorless	Odorless	Slightly salty	0.05	10	19.0
S31	Yellow	Odorless	Salty taste	4.20	200	19.1
S32	Yellow	Musty smell	Salty taste	5.01	500	19.1
S33	Colorless	Odorless	Tasteless	5.44	400	19.1
S34	Colorless	Odorless	Tasteless	1.41	100	19.0
S35	Colorless	Odorless	Tasteless	0.04	30	19.1
S36	Turbid yellow	Muddy	Salty	10.79	670	19.1
S37	Colorless	Odorless	Tasteless	1.23	150	19.0
S38	Colorless	Odorless	Tasteless	0.09	30	19.0
S39	Colorless	Odorless	Tasteless	0.41	60	19.1
S40	Colorless	Odorless	Tasteless	0.16	30	19.0
S41	Colorless	Odorless	Tasteless	0.08	40	19.0
S42	Colorless	Odorless	Salty	0.59	95	19.1
S43	Colorless	Odorless	Tasteless	0.66	180	19.1
S44	Colorless	Odorless	Slightly salty	0.61	160	19.0
S45	Colorless	Odorless	Tasteless	0.06	80	19.0
S46	Turbid yellow	Musty smell	Salty musty taste	16.64	570	19.1
S47	Yellow	Sewage-like odor	Salty	1.19	190	19.0
S48	Colorless	Odorless	Tasteless	0.03	20	19.1
S49	Colorless	Odorless	Salty	0.15	40	19.2
S50	Pale yellow	Odorless	Salty taste	4.14	290	20.1

Table 2 (continued)

Sample code	Color	Odor	Taste	Turbidity (NTU)	TSS (mg/L)	Temperature (°C)
S51	Colorless	Odorless	Tasteless	0.04	50	19.5
S52	Colorless	Odorless	Tasteless	0.08	30	19.5
S53	Colorless	Odorless	Tasteless	0.85	97	19.4
S54	Colorless	Odorless	Tasteless	0.46	30	19.2
S55	Colorless	Odorless	Tasteless	0.02	0	19.5
S56	Pale yellow	Odorless	Tasteless	0.60	120	19.5
S57	Colorless	Odorless	Tasteless	0.53	90	19.3
S58	Colorless	Odorless	Tasteless	0.09	30	19.3
S59	Colorless	Odorless	Tasteless	0.04	20	19.3
S60	Yellow	Odorless	Tasteless	0.10	50	19.3
S61	Colorless	Odorless	Tasteless	0.12	35	19.3
S62	Colorless	Odorless	Tasteless	0.11	30	19.4
S63	Colorless	Smelly	Tasteless	0.05	20	19.3
S64	Colorless	Odorless	Tasteless	0.64	100	19.4
S65	Colorless	Odorless	Tasteless	0.31	21	19.4
S66	Colorless	Odorless	Tasteless	0.03	19	19.2
S67	Colorless	Odorless	Tasteless	0.40	75	20.0
S68	Colorless	Odorless	Tasteless	0.12	41	19.8
S69	Pale Yellow	Odorless	Tasteless	0.55	110	19.7
S70	Colorless	Odorless	Bitter taste	0.28	65	19.7
S71	Colorless	Odorless	Tasteless	0.11	54	19.8
S72	Colorless	Odorless	Tasteless	1.35	80	20.1
S73	Colorless	Odorless	Tasteless	0.05	10	19.7
S74	Colorless	Odorless	Tasteless	0.08	20	19.9
S75	Colorless	Muddy smell	Tasteless	0.17	35	20.1
S76	Colorless	Odorless	Tasteless	0.14	20	20.0
S77	Colorless	Odorless	Slightly salty	0.58	75	20.0
S78	Colorless	Odorless	Tasteless	0.88	60	20.2
S79	Colorless	Odorless	Salty	0.41	75	20.1
S80	Colorless	Odorless	Tasteless	0.41	95	20.1
Mean ± SD				0.9425 ± 2.3517	95.525 ± 125.09	20.5938 ± 1.8418
Minimum				0.00	0.00	18.90
Maximum				16.64	670.00	23.40
WHO standard	Colorless	Acceptable	Acceptable	<5 NTU	–	–
PS	Colorless	Acceptable	Acceptable		–	–

*WHO-World Health Organization (WHO, 2017); *PS-Pakistan Standard

2012). This issue indicates that people are not well aware that poorly maintained water storage tanks could be a significant contributor of contaminated water. The large number of open abandoned boreholes (more than 72 were found in the study area) is also likely to provide preferential-pathways to allow surface contamination to be rapidly transported into groundwater.

Physiochemical analyses showed that pH, major cations and anions were at levels that are considered to be suitable for potable use. The major-ion analyses showed that the chemical composition of groundwater is dominated by bicarbonate ions. More detail is given in the Tables and spatial distribution diagrams that are presented in the electronic supplementary material.

Turbidity in water samples showed no significant correlation with other analyzed parameters except physical appearance that was identified as objectionable in some samples (high turbidity). Majorly Qila dedar Sigh and Rahwali showed high turbidity than the recommended value of WHO (5NTU) due to old redundant boreholes (boreholes instability: corrosion, damaging of casing/screen and wall collapse) which provide preferential pathway to contaminants and soil grains to slump/collapse into the groundwater.

Table 3 Descriptive statistics of groundwater quality parameters

Parameters	Minimum	Maximum	Mean ± SD	WHO Standards	PS
Chemical analysis					
pH	7.03	8.3	7.5 ± 0.30	6.5–8.5	6.5–8.5
TDS (mg/L)	112	1145	537.26 ± 276.33	< 1000	< 1000
TS (mg/L)	150.80	1438.0	632.79 ± 320.28	–	–
EC (μS)	187	1964	900.67 ± 469.75	–	–
Total alkalinity (mg/L)	86	734	358.65 ± 156.556	–	–
Hardness (mg/L)	86	690	311.15 ± 133.186	–	< 500
Ca^{+2} (mg/L)	24.8	172.0	69.950 ± 30.632	–	–
Mg^{+2} (mg/L)	5.76	86.4	32.872 ± 15.34	–	–
Na^{+} (mg/L)	26.00	377.14	122.03 ± 72.851	–	–
K^{+} (mg/L)	2.50	119.11	9.5483 ± 12.902	–	–
Cl^{-} (mg/L)	3.998	189.66	66.024 ± 48.02	–	< 250
SO_4^{2-} (mg/L)	.275	247.32	54.156 ± 52.241	–	–
HCO_3^{-} (mg/L)	103.2	893.28	434.829 ± 190.98	–	–
Heavy metal analysis					
Co (mg/L)	0.0000	0.0500	0.009965 ± 0.101081	–	–
Cu (mg/L)	0.0095	1.2328	0.031583 ± 0.1362319	2	2
Cd (mg/L)	0.0000	0.0235	0.001426 ± 0.0031540	0.003	0.01
Ni (mg/L)	0.0000	0.04	0.0094 ± 0.00905	0.02	≤ 0.02
Zn (mg/L)	0.0000	0.5000	0.017095 ± 0.0581412	3	5
Cr (mg/L)	0.00	2.00	0.2738 ± 0.34448	0.05	≤ 0.05
As (mg/L)	0.0000	0.1000	0.016125 ± 0.0258889	0.01	≤ 0.05
Microbiological analysis					
Fecal contamination	0 colonies	> 300 colonies (NTC)	–	Must not be detectable in any 100 ml sample	Must not be detectable in any 100 ml sample

PS Pakistan Standard (WHO 2017), *WHO* World Health Organization (WHO, 2017), *NTC* numerous to count

Table 4 HRI of heavy metals Cd and As for water samples exceeding permissible limits

Values	HRI			
	Cd		As	
	Child	Adult	Child	Adult
Minimum value	0.22	0.19	1.13	0.96
Maximum value	1.59	1.36	11.29	9.66

Mechanical faults in pipe distribution systems not only provide a basis for bacteriological contamination but can also increase dissolved solids levels in water. Moreover, seepage from open waste dumps (including animal wastes) may contaminate groundwater with a range of chemical constituents including soluble salts and ammonium ions. Some areas of Kamoki showed high hardness levels that causes scale deposition in sample bottles due to the high Ca ion concentrations in water. While other cations like Na^{+} and K^{+} were also observed in the areas of Sadhoke, Kamoki and Eminabad due to high TDS concentration and EC. On the other hand anions like Cl^{-} and SO_4^{2-} concentrations were also observed to be high, due to old and improper drainage systems and agricultural practices, in the areas of Khiali and Sadhoke.

Other elements of health concern in groundwater are elevated concentrations of metals which are significant contaminants in many parts of Pakistan. Earlier report by PCRWR (2007) also declared Gujranwala as among the six most vulnerable areas in Punjab as regards the presence of toxic metal in ground water.

The present study indicates that thirty-four water samples exceeded regulatory limits for As and Cr, while nine samples for Cd and 12 samples for Ni were in excess of the recommended WHO and Pakistan drinking water criteria possibly due to the discharge of untreated wastes from industries, agricultural fields and municipalities. Moreover, poor sanitary practices and abandoned boreholes may also one of the reasons behind heavy metals infiltration into groundwater. The trend of metal concentration in drinking water is Cr > Cu > Zn > As > Co > Ni > Cd. In a recent study, higher levels of trace elements such as As, Cr, and Ni have been reported

Table 5 Summary of questionnaire results

Question	Findings	Comments
Water source	99% locals use groundwater as drinking water source 1% household use bottled drinking water	Most of the households in selected areas get water from private boreholes (donkey pumps). Only one household consume bottled drinking water for consumption but not at regular basis. Some people also get water from community filter plants or from community hand pumps (only for drinking purpose). In very few areas government-supplied water but alternative source as private boreholes were also observed in these areas. So it is concluded that almost every household has its own motor driven pumps
Water service (24-hours)	100% locals rely on their own borehole pumps	Motor driven pumps provide 24 h water while government provide water at specific timings due to which people prefer their own source of water.
Sanitary services	70% residents are facing poor sanitation services along with inadequate cleanliness	Most of the people complained about the heaps of garbage strewed outside at open spaces (open municipal waste dumping and cow dungs in open field). Moreover, old cross-connected eroded sewerage and water pipe lines are present in the whole selected area
Depth of bore	Depth varies	Depth of bore varies from 15.24 m deep to 182.88 m deep
Water storage tank/containers	100% locals use storage tanks	Most of the people store water for emergency conditions. 100% people store drinking water in a drinking water container. Some of them take care of water storage hygiene
Common diseases	100% people experienced diarrheal disease, nausea and vomiting.	People in selected zones of Gujranwala District are mostly suffering from diarrheal diseases like cholera, vomiting, nausea, dysentery, gastroenteritis, laxative effect, abdominal pain etc. Mostly infants are reported to suffer from diarrheal infections. 37.5% household interviewed said that in the last 5 years someone or other in their family suffered from infectious hepatitis. 12.5% households reported skin and eye infections and 25% households reported typhoid in some family member in the last 5 years

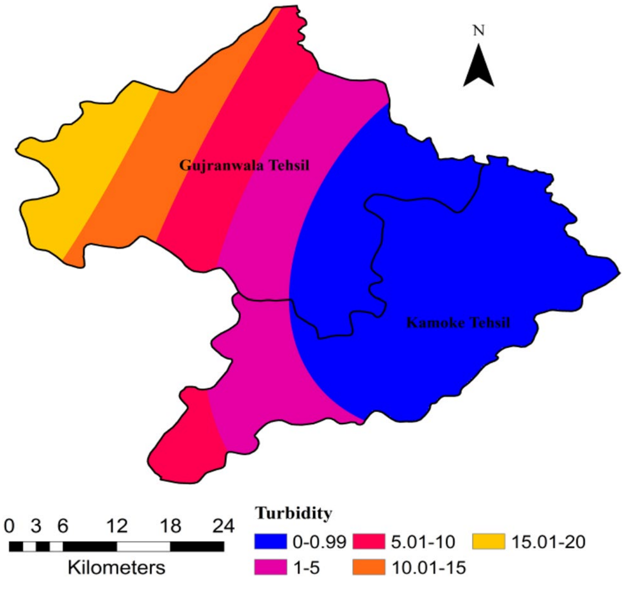

Fig. 2 Spatial distribution pattern of turbidity (NTU) in study area

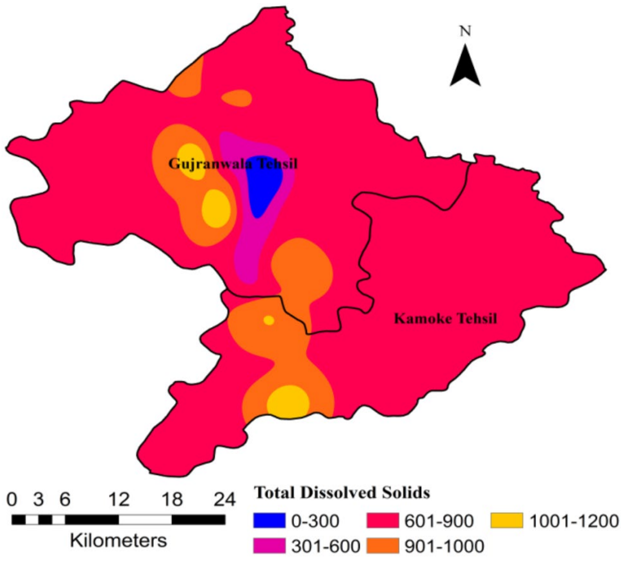

Fig. 3 Spatial distribution patterns of TDS (mg/L) in study area

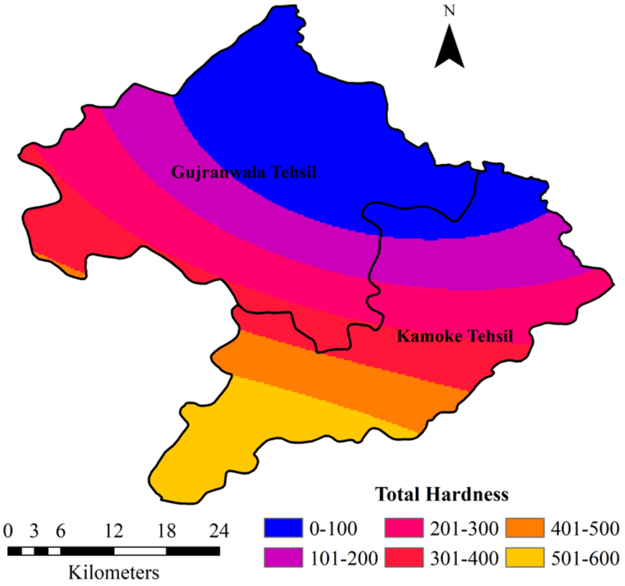

Fig. 4 Spatial distribution pattern of EC (μS) in study area

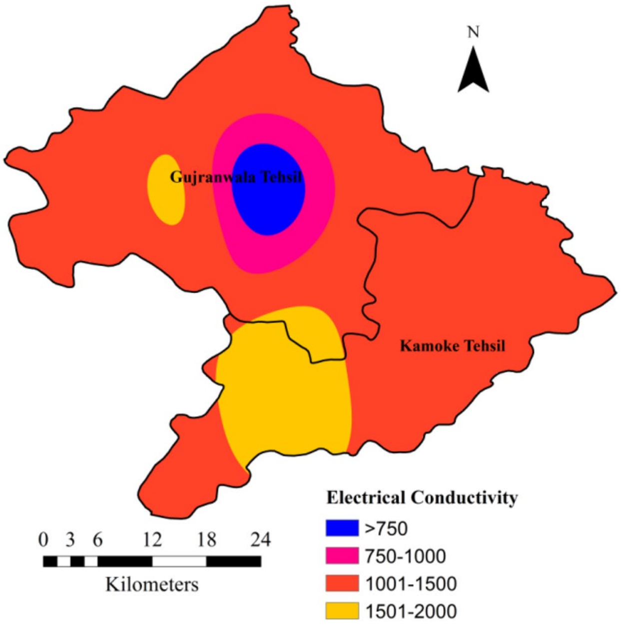

Fig. 5 Spatial distribution pattern of total hardness (mg/L) in study area

in other cities (Lahore, Jhang, vehari and Multan) of Punjab also (Hussain et al.2019).

Health risk index calculation that were carried out showed potential for health risk due to the presence of Cd and As in drinking water samples. For As, 34 samples showed HRI > 1 for child and 21 samples HRI exceeded value for adults. For Cd, only one sample showed HRI > 1 for both child and adult. A high consumption of As in drinking water or food is associated with adverse health impacts such as skin disorders, cardiovascular diseases, lung cancer, arsenicosis and male infertility etc. Rahman et al.2016; Milton et al. 2004)] while exposure to high levels of Cd leads to kidney failure, skeletal damage and cancer (Jaishankar et al. 2014; Malik et al. 2010). HRI values for Ni and Cr were less than 1.

Conclusions and recommendations

Based on the results of groundwater samples analysis and the questionnaire survey, it is concluded that most of the groundwater used for potable supply in the study area is significantly bacteriologically contaminated although a few samples were also considered to be unsuitable for drinking purposes due to high level of turbidity, TDS, hardness, FC and heavy metals (Cd, Ni, Cr and As). Presently, groundwater that is pumped from many boreholes is not suitable for portable use because of microbiological contamination and the results of a public survey showed the prevalence of water-borne diseases among local residents. It is likely that shallow groundwater is being continuously contaminated from external sources including infiltration through abandoned boreholes and cross-connected and eroded sewerage and water pipe lines that pollute groundwater with a high fecal load, as has been illustrated earlier also (PCRWR 2005; Shar et al. 2008). High Na and Cl concentration in some samples affect the taste of water quality (salty) and elevated metal concentrations also have the potential to cause health impacts on local residents.

A number of immediate management measures could be considered to reduce health impacts on local residents. These include decommissioning redundant boreholes in the area and disinfecting water used for potable use. Moreover, optimal groundwater management (monitor groundwater abstraction and recharge rate) and improved sanitation facilities are also essential in order to reduce the risk of waterborne diseases. A groundwater regulatory framework (Water Safety Plan) should be devised for the Gujranwala area with the collaboration of district government to avoid further deterioration of groundwater. Presently both corrective and preventive measures should be taken in the area to control the groundwater contamination. The correction actions include closing of abundant boreholes, treatment (chlorination, etc.) of contaminated water, changing of old water supply lines with HDPE pipes, construction of sanitary landfills, etc. The preventive actions include awareness to public to safe natural mineral water, treatment plants for sewage water, dumping of municipal solid waste on scientific grounds or recycling. In short, delineate protection zone for groundwater and improve sanitary and hygiene practices to avoid potential contamination risks.

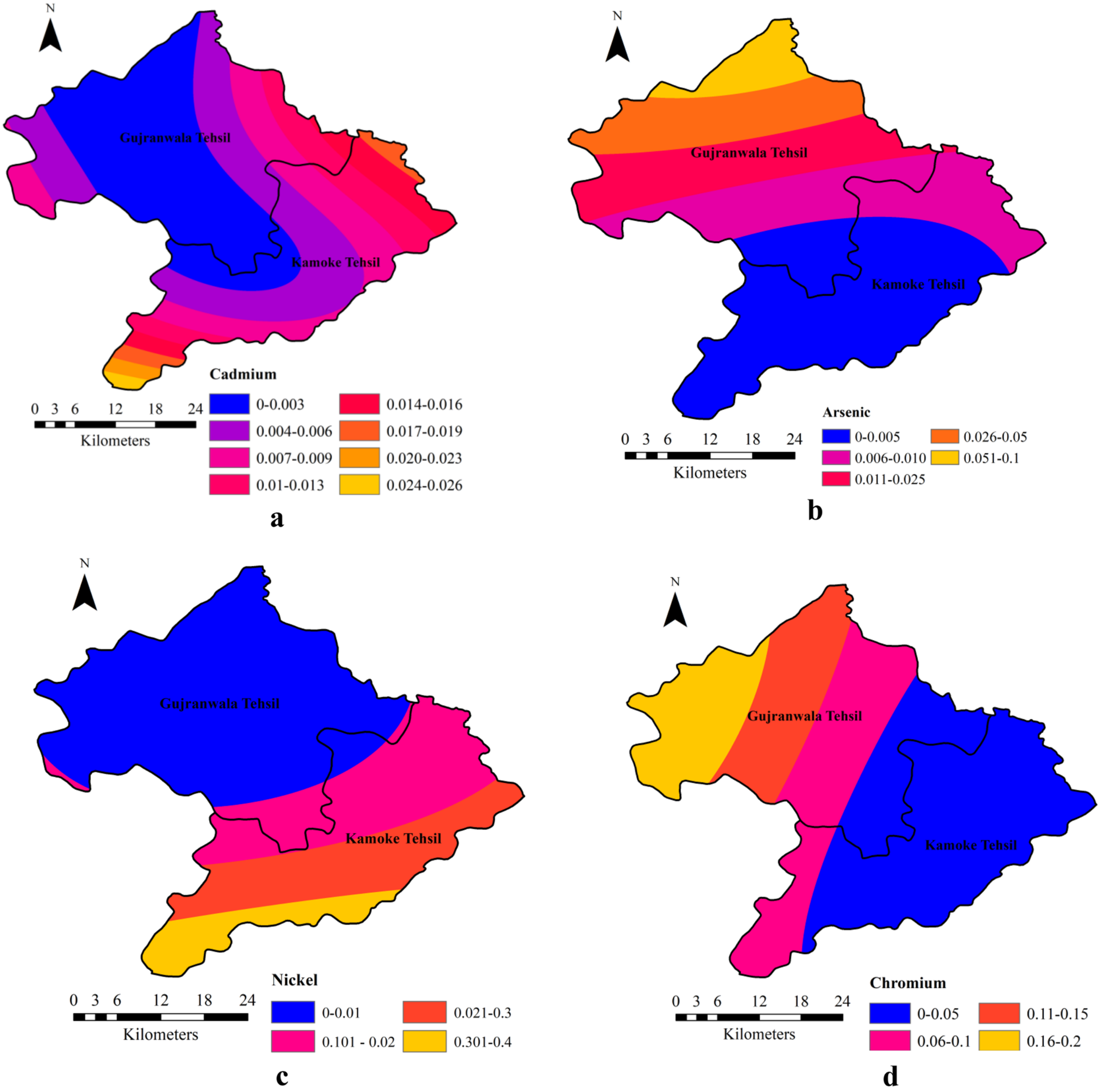

Fig. 6 Spatial distribution patterns of heavy metals exceeding WHO standard and PS

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