

ASSESSMENT OF GROUNDWATER QUALITY AND ASSOCIATED HEALTH RISKS IN RURAL AREAS OF SINDH (PAKISTAN)

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ABSTRACT. Groundwater quality has considerable impact on public health, especially in areas where majority of the people rely on groundwater for drinking purpose. In this scenario, investigation of 175 groundwater samples collected from district Jacobabad and Kashmor, Sindh Pakistan was carried out for physicochemical parameters (color, odor, taste, pH, EC, turbidity, alkalinity, hardness, Cl, SO₄⁻², NO₃⁻ and TDS), major cations (Na⁺, K⁺, Ca⁺² and Mg⁺²), trace elements (F, As, Fe and Zn) and microbiological organisms (*total coliform* and *faecal coliform*). Analysis results showed high level of microbial contamination as 66 and 62% sampling sites were laden with *total coliform* and *faecal coliform* organisms respectively. On the other hand, chemicals constituents like hardness, Ca, Mg, Na, K, SO₄, Cl, and TDS in 54, 72, 21, 47, 25, 73 and 49% water samples respectively were higher than GVs. Other than this, trace elements like F, Zn, As and Fe were also found in high concentration in 11, 04, 22 and 53% water samples respectively. Health risk assessment due to Fe, As and Zn revealed that arsenic HRI>1 in 22 and 13% water samples for children and adults respectively and overall CDIs and HRI were found in the order of As>Zn>Fe whereas, pollution index (Pi) for Fe was significant among all trace elements investigated.

Keywords: Contamination; pollution index; risk assessment; trace metals; groundwater.

INTRODUCTION

Quality of groundwater, the major source of drinking water and household use [1] is deteriorated by a number of things including materials on seepage routes, general human activities, sewerage or disposal system

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and dissolved solids and minerals. Flooding, one of the major natural disasters causes contamination of water by mixing different kinds of contaminants like industrial, human and animal wastes into the water body through unprotected bore holes and surface water sources. Waterborne diseases are the major threat to the healthy lives of the people. Literature shows that waterborne disease as a result of *faecal* pollution of drinking water wiped out entire population of cities [2]. It is estimated that nearly 80% of total diseases like diarrhea, dysentery, hepatitis, tooth decay and anemia in children are due to consumption of poor quality water [3]. In Pakistan over 40% of urban deaths are linked to waterborne diseases originated due to consumption of contaminated water [4]. A number of studies have been documented on severe contamination of drinking water sources with hazardous pathogenic bacteria like *Shigella sp.*, *V. cholerae*, *P. aeruginosa*, *Salmonella*, and *S. aureus* in different areas of Pakistan caused by recent floods, which have resulted diseases like diarrhea, cholera, typhoid fever, food poisoning, dysentery, gastroenteritis, and other serious infections [5-8].

Minerals and micronutrients are considered to be an essential part of drinking water but their excess beyond certain limit causes serious health implications. Calcium is considered to be an important component of basic structure of bone, soft tissues and teeth but its excess intake can interact with iron, magnesium, zinc, and phosphorus within the intestine and reduces their absorption. Higher concentrations of sulphate along with sodium and magnesium impair water taste and have laxative effect. Similarly, high concentration of sodium aid in increasing consumer's blood pressure. It has been reported that all hand pumps and 73% well water are not potable due to excess of nitrate, magnesium and sulphate in district Bannu (KPK), Pakistan [9].

Trace elements like fluoride, iron, zinc and arsenic can cause complex health hazards if ingested in excess for prolonged time, therefore, it is necessary to estimate potential health risk associated with these elements. Different studies conducted to evaluate heavy metal concentration and health risk assessment showed that overall all of these metals in excess concentration are toxic [4], [10]. Due to ingestion of As rich water, it is estimated that about 200 million people globally are at the health risk of As poisoning [11]. A number of other investigations have also been carried out to evaluate physicochemical and microbiological quality of drinking water and possible health risks [8], [12-15]. Similarly, high concentration of different minerals and trace metals have also been highlighted in a recent study conducted in district, Rajanpur, Pakistan [16]. Physicochemical and microbiological investigation of drinking water quality and possible health risks assessment have been carried out through a number of other studies

which revealed that most of water samples have chemical and/or microbiological contamination and are unsuitable for human consumption as found in Pakistan [13-14], [17], Cambodia [18], Ghana [19], Bangladesh [20], Romania [21], and many other Asian and European countries along with USA [22, 23].

In order to explore post flood groundwater profile, we have designed present research study to evaluate physicochemical and microbiological status and health risk associated with consumption of available potable groundwater in flood affected rural areas of district Jacobabad and Kashmor, Sindh, Pakistan.

RESULT AND DISCUSSION

Water samples collected under present investigated were evaluated for physico-chemical parameters (color, odor, pH, turbidity, conductivity, alkalinity, Cl^- , SO_4^{2-} , NO_3^- and TDS), major cations (Na^+ , K^+ , Ca^{+2} , Mg^{+2}), trace elements (Fe, F, As and Zn) and microbiological constituents (*total coliform* and *faecal coliform*) and finally analysis results were compared with guidelines values (GVs). Range and mean values of major water quality indicators are shown in **Table 1** whereas detail regarding sampling locations and variation of major water quality parameters as supplementary information can be available from the authors upon request.

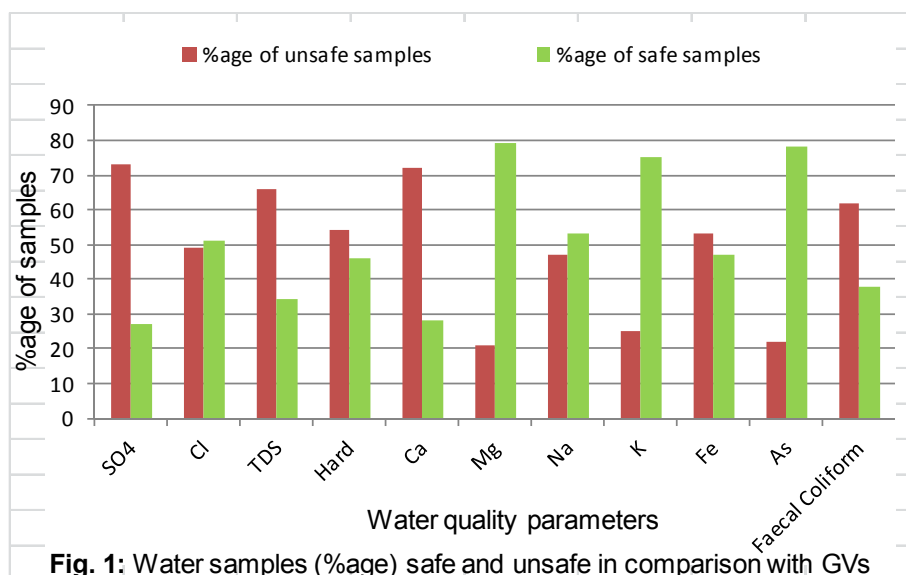
Physico-chemical parameters

Evaluation of physical and aesthetic indicators like taste, odour, colour and turbidity showed that most of the water samples were in agreement with GV's with the exception of a few having saline taste. Analysis data indicated that pH ranged from 6.60-8.26 which was in accordance with WHO GV's of 6.5-8.5 [2]. Conductivity is an indicator of ions concentration and their mobility, therefore, an increase in ion concentration increases EC of water [18]. In present investigation EC varied from 550 $\mu\text{S}/\text{cm}$ to 28040 $\mu\text{S}/\text{cm}$ which indicates high level of dissolved ionic concentration. Generally, conductivity of water samples collected from district Jacobabad was higher than Kashmor and highest value of 28040 $\mu\text{S}/\text{cm}$ was recorded for sample collected from village Rehmatullah Khoso. Alkalinity is also an important constituent of water but its concentration beyond certain limit is associated with problems like hardness, gas trouble, kidney stone, severe irritation of eyes, skin, and mucous membrane and damage of metallic pipes [24]. Analysis data showed that in presented study alkalinity ranged from 120-513 mg/L.

Table 1: Range and mean value of physico-chemical parameters

Parameter	Range	Mean	Parameter	Range	Mean
EC ($\mu\text{S}/\text{cm}$)	550-28040	3953	Na (mg/L)	34-2900	456
pH	6.60-8.26	7.4	K (mg/L)	2-130	12.2
Turbidity (NTU)	0.4-8.9	1.7	Ca (mg/L)	20-1280	218
Hardness (mg/L)	110-8550	1047	Mg (mg/L)	9.7-1446	122
Alkalinity (mg/L)	120-513	257	F (mg/L)	0.40-1.80	1.05
SO ₄ (mg/L)	32-3680	745	Fe (mg/L)	0.05-2.0	0.42
NO ₃ (mg/L)	0.01-12.6	1.38	Zn (mg/L)	0.50-4.50	1.06
TDS (mg/L)	315-14876	2414	As ($\mu\text{g}/\text{L}$)	0.0-15.35	5.05

Literature showed that elevated concentration of chloride may create problems in throat and digestive system along with imparting saline taste and corrosion problems [25]. Presented data showed that Cl ranged from 23-8575 mg/l and overall 49% water samples have high concentration of Cl than GVs. Higher Cl content was reported in water samples collected from villages Allah Dito, Lal Bux and Rehmatullah Khoso. The major portion of total hardness is caused by calcium and magnesium ions and its high level may instigate heart diseases in residents [26]. Hardness varied from 110-8550 mg/l and 54% water samples have higher level than WHO GVs. Similarly, it has been reported that people ingesting high SO₄ through drinking water may face diarrhea [27]. In present study SO₄ ranged from 32-3680 mg/l and overall 73% water samples possessed high SO₄ contents than WHO GVs. Seawater intrusion is considered to be responsible for pollution of groundwater systems with high Cl and hardness in Shah Bundar area [28]. Water samples collected from the house of Sohbat Khan, village Rehmatullah Khoso and Ramzan, Village Jabar and Rasoolabad has highest value of hardness and SO₄ respectively. Nitrate for only 02 water samples in presented data have high content than GVs. Literature shows that groundwater in Pakistan have very less concentration of nitrate, however, higher level may be reported due to different agriculture and non-agriculture sources [19]. High TDS is associated with taste, hardness, corrosion properties and tendency to incrustation. Presence of high concentration of Na, K, Ca, Cl, SO₄ and many more minerals contribute towards high level of TDS that may cause gastrointestinal exasperation [29]. In the presented study, TDS varied from 315 to 14877 mg/L and total of 115 (66%) water samples have TDS value higher than WHO permissible limit (**Fig. 1**).



Major cations

Although, metals like Na, K, Ca and Mg are responsible for carrying out very important physiological functions in human body but an unsuitable intake and consumption of these minerals may lead towards health implications. Literature shows that short term exposure to high concentration of Ca does not create any health implications, but long time intake may lead towards hypercalcemia, urinary tract calculi and calcification in kidneys and in arterial walls besides suppression of bone re-modeling [7]. High level of Na is associated with an increase in blood pressure in children, male and female of all ages [30]. Potassium is an important micronutrient for living organisms but, excess amount in drinking water may lead towards nervous and digestive disorder [31]. It has been reported that hard water due to the association of Mg with SO₄ ion may possess laxative properties and cause gastrointestinal disorders [15]. Presented data indicated that 72, 21, 47 and 25% water samples have high concentration of Ca, Mg, Na and K respectively (**Fig.1**).

Trace elements

Present study indicated that 04, 11, 23 and 53% water samples carry high content of Zn, F, As and Fe respectively (**Fig. 1**). Literature

presents that tooth decay and skeletal and non-skeletal fluorosis is associated with higher concentration of F in drinking water [32]. Intake of high contents of iron via food or drink may result toxic effects in human body. The formation of hydroxyl radicals and deposition of iron (due to these Fe^{+2} ions) in a typical kidney cell may harm kidney cells. The excess amount of iron may accelerate the formation of free radicals resulting in instigation of mutagenicity, nephrotoxicity and renal carcinoma [33]. Researcher documented that exposure to high level of As may cause hepatic, neurological, diabetic, hematological, cardiovascular, respiratory and reproductive effects in consumers. Carcinogenic symptoms including liver, skin, bladder, lung and kidney cancers are associated with exposure to high level of As [11]. In addition, consumption of arsenic contaminated water can also causes several noncancerous diseases such as liver disorders, hypertension, peripheral vascular diseases, diabetes mellitus and other respiratory and neurological issues [20].

Health risk assessment

Chronic daily intake (CDI) and health risk index (HRI) measurement for both children and adults were carried out to estimate health risk associated with ingestion of heavy metal as shown in **Table 2**. Calculated CDI values for Fe, As and Zn ranged from 0.002-0.061, 0.000-0.469 and 0.015-0.138 $\mu\text{g}\cdot\text{kg}^{-1}\cdot\text{day}^{-1}$ and 0.001-0.056, 0.000-0.426 and 0.014-0.125 $\mu\text{g}\cdot\text{kg}^{-1}\cdot\text{day}^{-1}$ for children and adults respectively. Calculated mean CDIs were found in the order of $\text{As} > \text{Zn} > \text{Fe}$.

HRI assessment showed that As HRI value is higher than other metals and overall 22 and 13% water samples have $\text{HRI} > 1$ for children and adults respectively indicating future consumer's health risk associated with consumption of polluted water for drinking purpose. HRI for Fe, As and Zn ranged from 2.18E-06 to 8.74E-05, 0.000-1.565 and 5.10E-05 to 4.59E-04 for children and 1.98E-06 to 7.94E-05, 0.000-1.421 and 4.63E-05 to 4.17E-04 for adults respectively which indicate that $\text{HRI} < 1$ for Fe and Zn. HRI calculations showed that heavy metals in ground water of district Rajanpur were found in order of $\text{As} > \text{Zn} > \text{Fe}$. Literature shows high to very high carcinogenic and non-carcinogenic health risk for both children and adults associated with elevated As concentration in drinking water and its correlation with Fe and other heavy metals [34].

Table 2: Calculated range and mean values of CDI and HRI of trace metals

		CDI		HRI	
		Children	Adults	Children	Adults
Fe	Range	0.002-0.061	0.001-0.056	2.18E-06 to 8.74E-05	1.98E-06 to 7.94E-05
	Mean	0.013	0.012	1.82E-05	1.65E-05
As	Range	0.000-0.469	0.000-0.426	0.000-1.565	0.000-1.421
	Mean	0.156	0.141	0.519	0.471
Zn	Range	0.015-0.138	0.014-0.125	5.10E-05 to 4.59E-04	4.63E-05 to 4.17E-04
	Mean	0.032	0.029	1.08E-04	9.78E-05

Pollution index (Pi)

The Pi data showed that Fe have shown significant pollution amongst all the studied trace elements (**Table 3**).

Table 3: Pi data of trace elements in water samples

Trace metals	Pollution index (Pi)
Fe	1.4
Zn	0.4
F	0.7
As	0.5

Microbiological monitoring

Present study revealed that 66 and 62% water samples are contaminated with *total coliform* and *faecal coliform* organism respectively as shown in Fig.1. Contamination of groundwater sources was evident from high level of open air defecation and practice of tethering animals close to human dwellings. Rain and flood water carry these human and animal's faecal wastes, which may carry pathogens and contaminates the water sources in the region and direct consumption from these sources may cause infectious diseases [28].

CONCLUSION

Physicochemical and microbiological assessment of groundwater being used for drinking purpose by residents of district Jacobabad and Kashmor revealed that there was high level of microbial contamination as 66% sites were found contaminated with *total coliforms* and another 62 %

were overloaded with *faecal coliform* bacteria. The study also highlighted that a large number of sampling sites were polluted with other chemicals, minerals and trace metals like Ca, SO₄, Na, K, Fe, As and TDS. Health risk assessment showed that HRI >1 for As in 22 and 13% water samples for children and adults respectively. Net result of present study is that most of the waterborne diseases prevailing in the region are due to consumption of substandard water after flood. A concrete policy should be devised to treat the ground water and address post-flood environmental effects on life and human health so that safety from hazardous effects associated with bacterial contamination and elevated concentration of toxic components may be ensured.

EXPERIMENTAL

Sampling location

Jacobabad and Kashmir are two adjacent districts of Sindh, Pakistan located at 28. 25 00°N & 68.8333°E and 28.4333°N & 69.5833°E respectively. A total of 175 water samples were collected from flood effected locations of both districts comprising 13 union councils and 47 villages as shown by highlighted areas on the map.

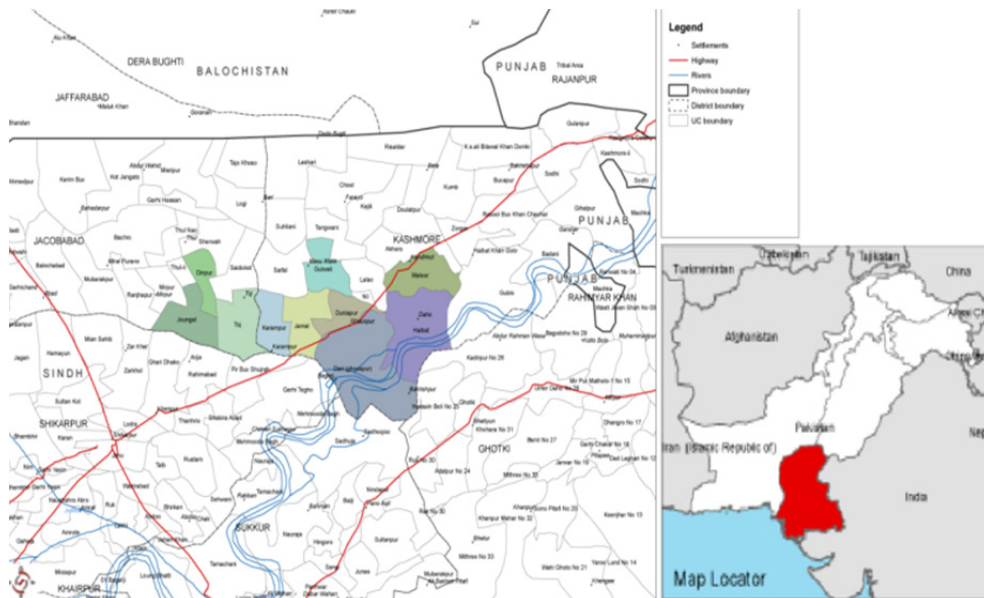


Fig. 2: Map of study area in district Jacobabad and Kashmir, Sindh

Water sample collection

From each sampling site, three water samples were collected in clean poly propylene bottles (600ml) for physico-chemical, trace elements and aesthetic parameters evaluation. Water sample for microbiological analysis were collected in sterilized bottles (250ml), stored in ice box and shifted to water quality laboratory for immediate analysis.

Reagent and instrumentation

All chemicals and calibration reagent used for the study were of analytical grade and calibration of all instruments was done prior to use. Instruments employed for evaluation of chemical parameters includes Louibond PCH63739 Germany turbidity meter, Jenway 350 EU pH meter,, HANNA HI 99300 Italy EC meter, Flame Photometer Italy, Optizen 2120 UV Plus Spectrophotometer, Mecasy Co. Ltd. Korea, HACH DR 2800 and Analytik Jena, AAS were used for analysis of chemical constituents and trace metals. Ca, Mg and hardness were estimated by complexometric titration method using EDTA whereas Cl was analyzed by following argentometric titration methodology. TDS was calculated by addition of cations and anions and *total coliform* and *faecal coliform* organisms were tested by membrane filtration technique.

Analytical investigation

Field testing instruments were employed for testing of aesthetic and physical parameters like color, taste, turbidity and pH at sampling site and analysis data was recorded. Chemical analysis of other water quality parameters including electrical conductivity (EC), hardness, calcium (Ca^{+2}), sodium (Na^{+}), magnesium (Mg^{+2}), potassium (K^{+}), nitrate (NO_3^{-}), sulphate (SO_4^{-2}), fluoride (F^{-}), alkalinity, chloride (Cl^{-}), iron (Fe), zinc (Zn), arsenic (As) and TDS was carried out at PCRWR water quality laboratory applying APHA standard methods after proper calibration and standardization of instruments [35].

Microbiological analysis

Analysis of *total coliform* and *faecal coliform* organisms was done by following membrane filtration technique [36]. Water sample (100ml) was filtered through sterile filter paper (0.45μ) using filtration assembly and placed on m-Endo and m-FC agar plates for analysis of *total coliform* and

faecal coliform respectively. Typical *coliform* colonies have pink to dark red colour with metallic sheen and *faecal coliform* colonies have blue colour which was counted after incubation of 24hrs at 35⁰C and 45⁰C respectively.

Health risk assessment

Health hazard associated with ingestion of heavy metals through drinking water was studied by calculating chronic daily intake (CDI) and health risk index (HRI) for both adults and children by using equation 1&2 respectively [37,38];

$$CDI = \frac{Mc \times Lw}{Wb} \quad (1)$$

$$HRI = \frac{CDI}{RfD} \times 0.001 \quad (2)$$

where Mc (ppb) is the heavy metal concentration whereas Lw (L/day) denotes daily water intake that is assumed as 1L/day for child and 2 L/day for adult and Wb (kg) is body weight of consumer that is considered as 32.7 kg and 72 kg for child and adult respectively [39]. RfD is the reference dose for oral toxicity which is 0.0003, 0.7 and 0.3 mg.kg⁻¹·day⁻¹ for As, Fe and Zn respectively, HRI is measured health risk index and 0.001 is the conversion factor used to downscale the reference dose (RfD) from mg to µg. Water samples having HRI<1 will be safe for consumption.

Pollution index (Pi)

Pollution index (Pi) is an important indicator for estimating relative pollution due to individual water samples and is calculated by following equation;

$$\text{Pollution index (Pi)} = \text{Concentration/Standard}$$

Significant degree of pollution is indicated by water samples having Pi >1 [40-41].

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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