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Investigation of Portable Groundwater Quality and Health Risk Assessment of Selected Trace Metals in Flood Affected Areas of District Rajanpur, Pakistan

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Abstract

Groundwater contamination is an important issue due to its toxicological effects on ecosystems and impact on public health. In this view, 120 water samples collected from flood affected areas of district Rajanpur, Pakistan were assessed for physical parameters (colour, odour, pH, turbidity and conductivity), minerals (Alkalinity, Na^{+}, K^{+}, Ca^{+2}, Mg^{+2}, Cl^{-}, SO_4^{-2} and TDS), micronutrients (F^{-}, As, Fe, Mn, Zn) and microbiological organism (*total coliform* and *faecal coliform*) to understand its suitability for human consumption and health risk associated. Analysis data revealed that 75 and 57% water samples were contaminated with *total coliform* and *faecal coliform* bacteria respectively. Other than this, a number of water samples were having high level of minerals, micronutrients and other chemical constituents. Health risk assessment due to high concentration of Fe, Mn, As and Zn was carried out by calculating chronic daily intake (CDI) and health risk index (HRI) for both adults and children separately. Calculated CDIs and HRIs were found in the order of Mn>As>Zn>Fe and As>Mn>Zn>Fe respectively. Results showed that HRI>1 for As in 46 and 37% water samples for children and adults respectively, posing serious threats to the healthy life of the local community.

Keywords: Groundwater; Contamination; Water quality; Risk assessment; Flood; Rajanpur; Pakistan

Introduction

Quality of ground water should be the leading research area for researchers as about 70% of Pakistanis are dependent on ground water for their household uses [1]. Ground water quality depends upon various things including different types of material on seepage routes, the dissolved solids and general human activities and sewerage or disposal system. Contamination of groundwater is done by different sources like natural disasters, fertilizers, residues of pesticides and other domestic and industrial wastes having different kinds of pollutants [2]. Flood, a common natural disaster, is among the main sources of water pollution which enter 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 [3]. It is estimated that nearly 80% of total diseases like diarrhoea, dysentery, tooth decay, hepatitis and anaemia in children are due to consumption of poor quality water [4]. In Pakistan over 40% of urban deaths are linked to waterborne diseases originated due to consumption of contaminated water [5]. A study conducted in Charsadda district of Khyber Pakhtunkhwa revealed that drinking water polluted with *coliform* bacteria was the main reason of common waterborne diseases like diarrhoea, gastroenteritis, dysentery and viral hepatitis in the region [6].

Minerals are an essential part of drinking water but excess of these beyond certain limit create complex health problems. Excess intake of calcium is directly associated with those who are prone to hypercalcaemia and milk alkali syndrome [7]. Calcium can also interact with iron, magnesium, zinc, and phosphorus within the intestine and reduces their absorption. Higher concentrations of SO_4 along with Na and Mg impair water taste and have laxative effect. Similarly, higher Na content aid in increasing consumer's blood pressure. It has been reported that all hand pumps and 73% well water are not portable due to excess of nitrate, magnesium and sulphate in district Bannu (KPK), Pakistan [8].

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 [9-11], Cambodia [12], Ghana [13] and Bangladesh [14]. In view of above mentioned scenario and importance of drinking water quality, present study was designed to evaluate physicochemical and microbiological status of drinking water in flood affected rural areas of district Rajanpur, Pakistan.

Materials and Methods

Water sampling

Household hand pumps in flood affected areas of district Rajanpur were targeted for investigation of water quality in rural areas of district Rajanpur. From each site, three water samples were collected in clean poly propylene bottles (600 ml) for physic-chemical, micronutrient and aesthetic parameters evaluation. Water sample for microbiological analysis from each site was collected in sterilized bottle (250 ml) and stored in ice box and shifted to laboratory for immediate analysis.

Analytical investigation

Aesthetic and physical parameters like colour, taste, turbidity and pH were recorded at the sampling site using respective field testing instruments and standard methods [15]. Chemical analysis of other parameters like calcium (Ca^{+2}), hardness, magnesium (Mg^{+2}), sulphate (SO_4^{-2}), fluoride (F^{-}), alkalinity, chloride (Cl^{-}), iron (Fe), arsenic (As)

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and TDS was done in PCRWR water quality laboratory applying APHA standard methods after proper calibration and standardization [15], whereas metals like zinc (Zn) and manganese (Mn) were determined by using palintest testing kit in the field. However, 10% water samples were analysed on atomic absorption spectrophotometer (AAS) for estimation of Zn and Mn and results were compared with field testing data.

Microbiological analysis

Analysis of *total coliform* and *faecal coliform* bacteria was done by adopting membrane filtration technique [16]. Water sample (100 ml) was filtered through sterile filter paper (0.45 µ) using filtration assembly and placed on m-Endo and m-FC agar plate for *total coliform* and *faecal coliform* analysis respectively. Typical *coliform* colonies have pink to dark red colour with metallic sheen and *faecal coliform* colonies have blue colour are counted after incubation of 24 hrs at 35°C and 45°C respectively.

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 analysis. Instruments and methods employed for evaluation of chemical parameters includes Jenway, 350 pH meter EU, HANNA HI 99300 Italy EC meter, Louibond PC_H63739 Germany turbidity meter, Ca, Mg, Cl, Alkalinity and Hardness by titration method. Na and K on Flame Photometer Italy and analysis of SO_4 and Fe were performed on Optizen 2120 UV Plus Spectrophotometer, Mecasy Co. Ltd. Korea. Fluoride was estimated on HACH DR 2800 Colorimeter and AAS were used for analysis of As whereas Zn and Mn were analysed using Palintest field testing kit and AAS. TDS was calculated by addition of cations and anions and *total coliform* and *faecal coliform* by membrane filtration assembly.

Health risk assessment

Chronic daily intake (CDI) and health risk index (HRI) of heavy metals was calculated by using the equation given below [17];

$$\text{Chronic Daily Intake}(\text{CDI}) = \frac{\text{Mc} \times \text{Lw}}{\text{Wb}}$$

Where, Mc (µg/L) is the metal concentration in water while Lw (L/day) is daily water intake that is considered as 1 L/day and 2 L/day for child and adult respectively, and Wb (kg) is body weight that is assumed as 32.7 kg for child and 72 kg for adult [18].

To address chronic health problems, the health risk index was calculated by using a modified form of equation [19].

$$\text{Health Risk Index}(\text{HRI}) = \frac{\text{CDI}}{\text{RfD}} \times 0.001$$

Where, CDI is chronic daily intake, 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, Zn and Mn respectively and HRI is measured health risk index, and 0.001 is the conversion factor for downscaling the reference dose (RfD) from mg to µg. HRI<1 will be the limit for safe mode of water consumption.

Results and Discussion

Water samples collected under present investigated were assessed for physical parameters (colour, odour, pH, turbidity and conductivity), minerals (alkalinity, Na^+, K^+, Ca^{+2}, Mg^{+2}, Cl^-, SO_4^{-2} and TDS), micronutrients (Fe, F^-, As, Mn and Zn) and microbiological constituents (*total coliform* and *faecal coliform*) and finally analysis results were compared with guidelines values.

Physical parameters

Physical and aesthetic parameters like taste, colour and turbidity of most of the water samples analysed were not objectionable with the exception of a few having saline taste. Ideally, drinking water should be colourless, odourless and tasteless. pH of all water samples collected and analysed ranged from 6.9-7.6 which is in close agreement with WHO guideline values of 6.5-8.5 [20].

Minerals assessment

Although, elements like Na, Ca and Mg are responsible for important physiological functions in human body but an unsuitable intake and consumption of these minerals may lead towards health implications. Ca is considered to be an important component of basic structure of bone, soft tissues and teeth. Literature showed 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 remodelling [21]. Present study showed that calcium ranged from 40-460 mg/L and overall 75% water samples were having high level of calcium than guideline limits as shown in Figure 1.

Total hardness is combination of Ca, Mg, Fe, Cl and SO_4 ions concentrations and its high level may instigate heart diseases in residents [22]. Similarly, higher contents of Cl in drinking water may create problems in throat and digestive system along with imparting saline taste and corrosion [23]. Alkalinity is also an important parameter of water quality but its concentration beyond certain limit causes many problems like hardness, kidney stone, gas trouble, damage of metallic pipes and severe irritation of skin, eyes and mucous membrane [24]. High level of Na is associated with an increase in blood pressure in children, male and female of all ages [25]. Present study revealed that overall 19, 7.5, 27, 24, 20 and 31.5% water samples have higher ionic concentration of Cl, Mg, hardness, Na, K and SO_4 respectively and rest of all water samples are in good agreement with WHO guidelines as shown in Figure 1.

High TDS is associated with taste, hardness, corrosion properties and tendency to incrustation. Presence of high concentration of Na, K, Ca, Cl, SO_4 and many more minerals contribute towards high level of TDS that may cause gastrointestinal exasperation [26]. In the presented study, TDS varied from 293 to 3633 mg/L and total of 29 water samples have TDS valued higher than WHO permissible limit as shown in Figure 2.

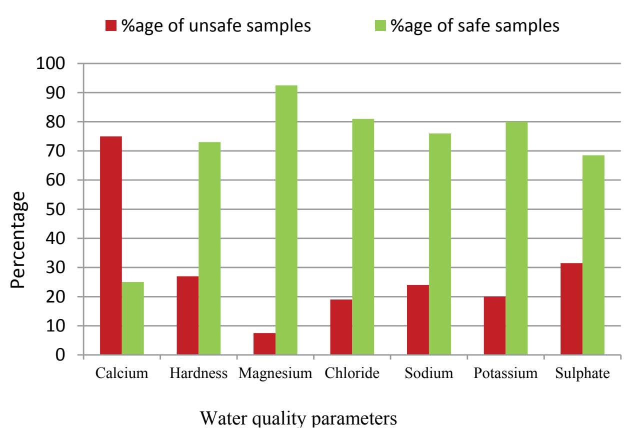

Figure 1: Water samples (%age) safe and unsafe as compared to GVs.

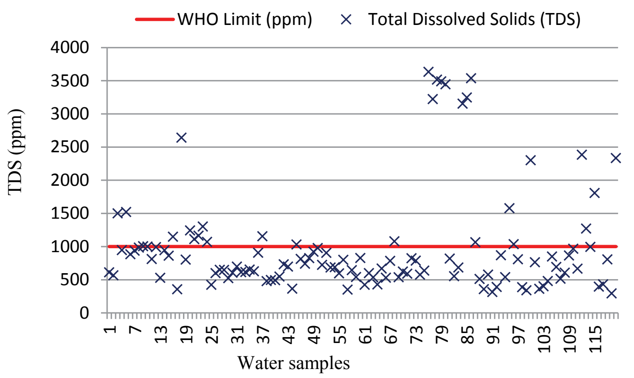

Figure 2: Comparison of measured TDS with WHO guideline value.

Micronutrients

Trace metal are associated with serious health implications depending upon the nature and quantity of the metal consumed, overall all of these metals in excess concentration are toxic [27]. Fluoride estimation in drinking water is important due to adverse health effects of its higher concentration like tooth decay and skeletal and non-skeletal fluorosis etc. among the natives [28]. Present study indicated that Mn and Zn values of all water samples analysed were within the permissible limits of WHO with the exception of 06 water samples having high concentration of zinc. On the other hand about 08, 42 and 60% water samples have higher content of F^-, As and Fe respectively as shown in Figure 3. It is believed that due to the interactions between the hydrological cycle and the biosphere and geosphere, the water sources used for drinking purposes generally contain natural organic matter (NOM) but during rainy season and floods its amount increases much more in surface and ground water inhibiting the oxidation of iron by reducing it from Fe^{+3} to Fe^{+2}, and as a result concentration of iron in water is increased. 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 [29].

Health risk assessment

In present study, health risk assessment due to elevated concentration of As, Fe, Mn and Zn in groundwater was carried out by measuring chronic daily intake (CDI) and health risk index (HRI) values for both children and adults as shown in Table 1. Calculated CDI values for children ranged from 0.003-0.092, 0.000-0.917, 0.000-0.807 and 0.015-0.138 $\mu g \cdot kg^{-1} \cdot day^{-1}$ and in the case of adults CDI varied from 0.003-0.083, 0.000-0.833, 0.000-0.733 and 0.014-0.125 $\mu g \cdot kg^{-1} \cdot day^{-1}$ for Fe, Mn, As and Zn respectively. Calculated CDIs were found in the order of Mn>As>Zn>Fe.

HRI values were high for As, ranging from 0.000-2.691 (mean=1.001) for children and from 0.000-2.444 (mean=0.909) for adults and overall 46 and 37% water samples have HRI>1 in children and adults respectively. HRI for Fe ranged from 4.37E-06 to 1.31E-04 and 3.97E-06 to 1.19E-04, Mn from 0.000-0.038 and 0.000-0.035 and Zn HRI varied from 5.10E-05 to 4.59E-04 and 4.63E-05 to 4.17E-04 for both children and adults respectively which indicate that HRI<1 for Fe, Mn and Zn. Comparison of mean HRI values for 08 union councils revealed that ground water of Kot Mithan, Noorpur and Sabzani union councils is more prone to health hazards as is evident from high mean HRI, which is greater than 1 for both children and adults as compared to other union councils as shown in Table 2 whereas mean HRI of As and other heavy metals is less than 1 in all other union councils. HRI calculations showed that heavy metals in ground water of district Rajanpur were found in order of As>Mn>Zn>Fe.

Groundwater samples having HRI>1 highlight future consumer's health risk associated with intake of this water for drinking purpose. Literature shows high to very high carcinogenic and non-carcinogenic health risk for adults and children associated with elevated As concentration in drinking water and its correlation with Fe and other heavy metals [30].

Microbiological monitoring

Pathogens associated with contamination of water sources pose an adverse health risks to men, women and children of all ages because nearly 80% of total diseases including diarrhoea, hepatitis, dental caries, oral hygiene and anaemia in children are associated with drinking contaminated water [31]. Study presented here showed that 75% water samples were found contaminated with *total coliform* whereas 57% were having *faecal coliform* organism as shown in Figure 4. 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 [32].

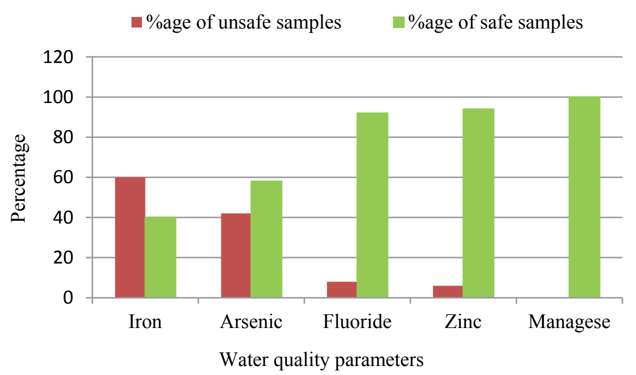

Figure 3: Samples (%age) safe and unsafe as compared to GVs.

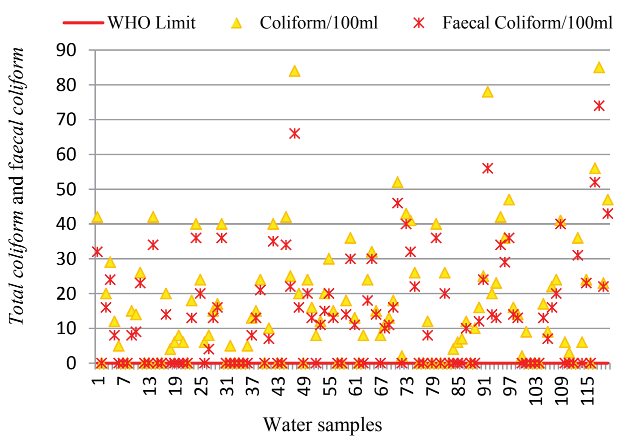

Figure 4: Comparison of *total coliform* and *faecal coliform* with WHO GVs.

Metals		CDI		HRI	
		Children	Adults	Children	Adults
Fe	Range	0.003-0.092	0.003-0.083	4.37E-06 to 1.31E-04	3.97E-06 to 1.19E-04
	Mean	0.017	0.016	2.47E-05	2.24E-05
Mn	Range	0.000-0.917	0.000-0.833	0.000-0.038	0.000-0.035
	Mean	0.621	0.564	0.026	0.024
As	Range	0.000-0.807	0.000-0.733	0.000-2.691	0.000-2.444
	Mean	0.3	0.273	1.001	0.909
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	0.034	0.031	1.13E-04	1.02E-04

Table 1: Calculated range and mean values of CDI and HRI of trace metals.

Union Councils	Fe HRI		Mn HRI		As HRI		Zn HRI	
	Children	Adults	Children	Adults	Children	Adults	Children	Adults
Jahanpur	2.77E-05	2.51E-05	0.025	0.023	1.009	0.917	1.26E-04	1.14E-04
Kot Mithan	2.21E-05	2.01E-05	0.028	0.025	1.145	1.040	9.24E-05	8.40E-05
Miranpur	4.69E-05	4.26E-05	0.027	0.025	0.867	0.787	9.51E-05	8.64E-05
Murgai	1.51E-05	1.38E-05	0.021	0.019	0.802	0.728	9.65E-05	8.77E-05
Norpur	1.67E-05	1.52E-05	0.027	0.024	1.333	1.211	6.80E-05	6.17E-05
Sabzani	3.51E-05	3.19E-05	0.026	0.023	1.566	1.422	9.85E-05	8.95E-05
Shakarpur	1.28E-05	1.16E-05	0.026	0.024	0.565	0.514	2.07E-04	1.88E-04
Wang	2.10E-05	1.90E-05	0.027	0.025	0.719	0.653	1.19E-04	1.08E-04

Table 2: Comparison of calculated HRI due to trace metals at union council level.

Conclusion

Physicochemical and microbiological assessment of groundwater being used for drinking purpose by residents of district Rajanpur revealed that there was high level of microbial contamination as 75% sites were found contaminated with *total coliforms* and 57% were overloaded with *faecal coliform* bacteria. The study also highlighted that a large number of sites were polluted with other chemicals, minerals and trace metals like Ca, SO_4, Na, K, Fe, As and TDS. Health risk assessment showed that HRI>1 for As in 46 and 37% 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.

Conflict of Interest

The authors declare no conflict of interest for compiling and submission of this article.

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