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Physicochemical Properties and Health Impacts of Flood and Post Flood on Drinking Water of Indus River System of Jamshoro, Sindh

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Abstract
In this study, the comparative analysis of water quality during the flood (phase-I) and post-flood (phase-II) was carried out to understand its health concerns on local communities. The water samples were collected during the flood (August) and after the flood (November) in 2013 from Manchar Lake and surroundings and analyzed for the various physical, chemical and microbial parameters. Health quotient (HQ) carcinogenic, chronic and dermal for arsenic, iron, cadmium, cobalt, zinc and copper were measured. The results showed that pH was within the WHO range, but phase-II (8.4) were more saline than phase-I (7.48). The electric conductivity and total dissolved solids were within the normal range except samples from Manchar Lake and River/Lake link. However, turbidity was higher in phase-I (450 NTU) compared to phase-II (311). Total hardness, calcium hardness, and sulfates were also higher in samples of phase-II. The concentrations of the heavy metals were found to be in the order Fe (9674 ppb) > Mn (4700 ppb) > Zn (1347 ppb) > Cu (989 ppb) > Ni (811 ppb) > Co (355 ppb) > Cd (213.6 ppb) > As (50 ppb) in phase-II and Zn (1229 ppb) > Cu (1076 ppb) > Ni (296 ppb) > Co (258.7 ppb) > Fe (155 ppb) > As (50 ppb) in phase-I, respectively. Health quotient (HQ) carcinogenic for arsenic was normal. HQ chronic for As and Fe were observed insignificant, while for Cd and Ni were found above the normal range in phase-II. It can be concluded that drinking water available to local residents during the flood and after the flood was unsafe for domestic use. There is an urgent need for strict monitoring to ensure the quality of water supply in flood affected areas of Sindh, Pakistan.

Keywords Indus River, flood, health impacts, physicochemical, heavy metals, Jamshoro.

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Introduction

Water, an essential element for all living things, has acquired growing concern from researchers worldwide. Water pollution from different sources is threatening public health in Pakistan. Drinking water sources are contaminated with heavy metals and microbes throughout the country. Physical, chemical and microbiological parameters set by the World Health Organization (WHO) standards are failing to comply and are the main factors responsible exclusively or in a combination of the various health problems. In the past few decades, water pollution from toxic metals has received greater attention, because it poses threat to public health as well as aquatic life [1].

Water pollution and environmental deterioration due to increased stress on the river is caused by urbanization, quick growth in population and development in beside river basin land areas [2]. Rivers of developing countries in the urban areas are on the end point of discharge effluents from industries [3]. Indus River is one of the main water distribution systems in Southeast Asia. It originates in the Himalayas and is approximately 2737 km long. After leaving the Himalayan Mountain, it travels about 1000 to 1200 km in the plains before flowing into the Arabian Sea. During its travel in the plains, it is joined by several tributaries [4]. The Indus River is polluted due to untreated municipal and industrial wastewater discharges; the Manchar Lake outflows make the pollution further obvious during periods of low flow (December-January). There are basically three sources which pollute the Indus River: (1) municipal wastewater discharge, (2) industrial waste water and (3) flows of come back-agriculture by drainage structures. Municipal wastewater from several major cities and towns of Sindh discharges into the Indus River [5]. Chronic disease and related conditions (CDRCs) can be exacerbated by disasters, increasing an individual's exposure to adverse health outcomes after a flood [6]. Flood water causes releasing of chemicals that are already present in the environment. Therefore, toxic exposure-related health impacts are greatest in populations living adjacent to flood-affected industrial or agricultural areas [7]. Flood water is contaminated with several chemicals and toxic metals and associated with gastrointestinal, liver, kidney, cardiovascular, and neurological diseases and cancer [8], rashes of skin, ear pain and other infectious diseases are widespread complaints after the flood [9]. Long-term mortality can be directly attributed to the flooding; such as increases in diarrheal deaths in low-income nations [10].

There is less scientific data available for analysis of water quality parameters during flood and post flood and its impact on local residents. However, there was a research carried out in pre-monsoon and post-monsoon seasons of district Thatta, Sindh [11]. This study was designed after hypothetical observation of increasing waterborne diseases in the surrounding areas. The current study was undertaken with the objectives to assess the physicochemical and biological parameters during flood and post flood in order to check its health concerns of local communities.

Material and Methods

Sampling area and pretreatment

This study was stretched from Manchar Lake along with its adjoining areas (Aamri, Dari Gaincha, Shalmani, Sann, Manjhand, Kotri and Almanzar) in Sindh, Pakistan. A total of 40 water samples were collected in two phases (twenty in each phase) with the gap of three months. Water samples in phase-I were collected during the flood session in August 2013, while samples in phase-II were collected after the flood in November 2013. Samples were collected from three locations including, Manchar Lake (M), River/Manchar link point (R/M), and Indus River and analyzed at Institute of Biochemistry and Hi-Tech Research Laboratory, University of Sindh, Jamshoro, Sindh, Pakistan. The water samples were collected by using sterilized Van Dorn plastic bottles (1.5 L capacity) and were reserved in well-stoppered polyethylene plastic bottles earlier soaked in 10% nitric acid (HNO_3) for 24 hours and rinsed with ultrapure water. All water samples were stored in insulated coolers containing ice and delivered on the same sampling day to the laboratory for analysis.

Physical parameter analysis

Appearance, color, and odor were identified by the senses. Turbidity and pH were determined by turbidity meter (Model: PC Chekit Lovibond, Germany) and pH meter (Hanna Instruments, HI 8417, Italy), respectively. Electric conductance (EC) and total dissolved salts/solids (TDS) were determined using conductivity meter Orion 115 (Orion, Inc, Boston, USA). Total hardness, Ca hardness, Cl, alkalinity were measured by titration and sulfates measured by double beam spectrophotometer.

Chemical parameters analysis

Arsenic was determined by HACH Arsenic kit (EZ Arsenic Test Kit 2822800; Hach Company, USA) for 0.01-0.5 mg/L. This test generates arsenic hydride, which reacts with the mercury bromide present in the analytical strip to form a yellow-brown miscellaneous arsenic mercury halogenide. The concentration of arsenic was analyzed through visual assessment of the reaction region of the analytical test strip with scales of fields of color [12]. Calcium (Ca) and magnesium (Mg) were measured by formula method, Silica was measured by double beam spectrophotometer, and chloride (Cl) was measured by titration. Other metals like cadmium, zinc, nickel, manganese, copper, cobalt, iron, potassium and sodium were measured using Perkin-Elmer atomic absorption spectrometer (AAS-PEA-700).

Biological parameter analysis

Microbiological test of Coliform was done using the most probable number (MPN) method [13].

Risk assessment

Eq. 1, adapted from the US Environmental Protection Agency (USEPA) was used to calculate the chronic daily intake of ingestion and dermal absorption pathways [14].

$$\text{CDI (dermal)} = \text{CW} \times \text{SA} \times \text{Kp} \times \text{ABSd} \times \text{ET} \times \text{EF} \times \text{ED CF} / \text{BW} \times \text{AT} \qquad \text{(eq. 1)}$$

Table 1 The full names of abbreviations used in eq. 1 and their values.

Abr	Parameters	Values	Reference
CW	Metal concentration in water (μg/L)	0-250	This study
BW	Adult body weight (Kg)	70	[15]
BW	Child body weight (Kg)	15	[15]
ED	Exposure duration (Adult)	70	[15]
ED	Exposure duration (Child)	6	[15]
EF	Exposure frequency (events/year)	365	[16]
SA	Skin-surface area (cm^2)	18000	[15]
SA	Skin-surface area (cm^2)	6600	[13]
CF	Conversion factor (L/cm^3)	1/1,1000	[16]
AT	Average time (days)	25,550	[16]
AT	Average time (days)	2,190	[16]
AbSd	Dermal absorption factor	0.001 (for As 0.03)	[17]

Abr = abbreviations; Full name and values of Kp are given in Table 2.

The abbreviations used in eq. 1 are shown in Table 1. In order to estimate the daily exposure of an individual, Eq. 2 is the representation of daily exposure via ingestion route. Eq. 2 adapted from the

USEPA was used to calculate the chronic daily intake (CDI, µg/kg/d) [18].

$$CDI = C \times DI / BW \quad \text{(eq. 2)}$$

Where
CDI = chronic daily intake (µg/kg/d)
C = contaminant concentration (ppb)
DI = daily intake of drinking water (L/day)
BW = body weight (kg)

The HQ for non-carcinogenic (chronic) risk was calculated using the following eq. 3 [19].

$$HQ = CDI / RfD \quad \text{(eq. 3)}$$

Cancer hazard (HQ carcinogenic) linked to intake contact was calculated by means of the subsequent formula [20]:

$$R = CDI \times SF \quad \text{(eq. 4)}$$

Where R is the surplus possibility of excess lifetime cancer as a consequence of contact with a contaminant (or cancer risk). SF is a cancer slope factor and its value is 1500 µg/kg/d for arsenic. By the USEPA, Risk (R) value above than one in a million (10^{-6}) is considered intolerable [18]. In contrast, along with national standards and environmental policies, this permissible range could change and possibly as increase as 10^{-4} [19-21]. The SF and RfD standards were obtained from the USEPA (Table 2) [22]. When the HQ values were >1, the health risk generally occurs [23].

Table 2 Reference dose (Rfd) dermal and reference dose ingestion and permeability coefficient (Kp) for different metals [15, 16].

Element	RfD dermal (µg/kg/day)	RfD ingestion (µg/kg/day)	Kp (cm/hour)
Ni	5.4	20	29E-4
As	0.123	0.3	1.00E-3
Cd	0.005	0.5	1.10E-0
Cu	12	40	19E-3
Co	0.003	-	49E-4
Cr	0.015	3	29E-3
Fe	45	300	19E-3
Mn	0.8	20	-

Results and Discussion

Physical parameters

Color, taste, odor

Water is used as a macronutrient, but in a drastic condition like flood, it becomes worse and creates diseases in the community. In this study, all water samples were colorless and odorless except the samples from Manchar Lake. All samples from phase-II and more than half samples (12) from phase-I were saline.

pH

The pH of all samples of phase-I and phase-II was found within the WHO range and Pakistan standards for drinking water which is 6.5 to 8.5 [24]. The pH was higher in phase-II than phase-I, but was below the normal range. The pH of water samples varied from 8 to 6.52 and 8.4 to 7.5 in samples of phase-I and phase II, respectively. It may be presumed that drinking water after flood available to residents was salty in nature but within the permissible limit for drinking uses.

EC, TDS, salinity and alkalinity

EC and TDS are an indication of the inorganic load of any water body. There is no standard value for EC provided by the Pakistan Council of Research in Water Resources (PCRWR) and WHO. However, a value of < 1000 µS/cm is recommended for EC, which is generally equivalent to the TDS value of <500 mg/L (1562 µS/cm for TDS value of 1000 mg/L set by WHO) and considered to be the highest permissible limit suggested in PCRWR standards [25]. The EC and TDS concentrations were within the WHO safe limits in both phases except the samples of Manchar Lake and River/Lake link. The EC value of drinking water ranged from 628 µS/cm to 300 µS/cm and 820 µS/cm to 532 µS/cm in samples of phase-I and phase-II, respectively. The maximum and minimum TDS concentrations were 401.92 mg/L and 192 mg/L, and 524.8 mg/L and 340.48 mg/L in samples of phase-I and phase-II, respectively, except the samples from Manchar and River/Lake Link. However, TDS was higher in samples of phase-I (3187.2 mg/L) than phase-II (2195.2 mg/L) in samples from Manchar Lake and vice versa for samples from River/Lake Link (199.68 mg/L in samples of phase-I and 2259.2 mg/L in samples of phase-II). Likewise, EC was greater in water samples of phase-I (4980 µS/cm^3) than phase-II (3430 µS/cm) and conversely for samples from River/Lake Link (312 µS/cm in samples of phase-I and 3530 µS/cm in samples of phase-II). The salinity ranged from 2.7 to 0.1 and 1.8 to 0.3 in samples of phase-I and II, respectively. The value of alkalinity for drinking water has no set guideline value. Alkalinity identified was elevated in phase-II samples of Manchar Lake and River/Lake link. It varied from 210 mg/L-120 mg/L in phase-I and 545 mg/L-120 mg/L in phase II. Higher EC may be due to high salinity and high mineral content at the sampling points. A Higher level of TDS reduces the tastiness of drinking water and may cause gastro-intestinal problems in human and may also have a laxative effect particularly upon transits [26].

Turbidity

Turbidity is usually due to suspended particles of clay or slit in the water and may be caused by a number of colloidal organic or inorganic materials. The occurrence of turbidity of surface water may be permanent or seasonal. The normal WHO turbidity limit in drinking water is <5 nephelometric turbidity unit (NTU). The turbidity observed in all samples was above the WHO water quality standards. The maximum turbidity range was 450 NTU and minimum was 136 NTU irrespective of phase variation. Similar results were reported in which water samples were found more turbid collected during monsoon season (July-September, 2002) [11]. The high turbidity is usually associated with higher levels of disease-causing microbes and indirectly constitutes a health issue.

Total hardness and calcium hardness

Total hardness in water is mainly due to the presence of calcium, magnesium, carbonates, bicarbonates, chlorides and sulfates. The WHO and PCRWR standards for total hardness and calcium hardness in drinking water is 500 ppm and 250 ppm, respectively. The maximum and minimum total hardness were observed 860 mg/L and 150 mg/L, and 1030 mg/L and 450 mg/L in water samples of phase-I and phase-II, respectively. Total hardness was higher in 12 samples of phase-I and all samples of phase-II than the WHO range of 400 mg/L. Calcium hardness was ranged from 370 mg/L to 90 mg/L and 600 mg/L to 150 mg/L in samples of phase-I and phase-II, respectively. Calcium hardness except in Manchar Lake samples was found within the normal range in Phase-I and except 4 samples out of 20 found above the WHO normal range 175 mg/L, which reflects post-flood effects on water quality. Elevated water hardness mainly contributes to economic damages such as corrosion and choking off the pipes and utensils. It has been reported in previous studies that elevated hardness may cause diarrhea, gas trouble, kidney stones, and heart problems [27, 28]. It's recommended to boil water for the better taste in order to reduce the Ca and Mg dissolved content/hardness of the water samples of origin.

Sulfate

Sulfate (SO_4^{2-}) is also one of the major inorganic components of drinking water which may deteriorate the water quality. The sources of sulfate in water are mainly calcium sulfate and sodium sulfate. Sulfate contributes to the permanent hardness of water. Sulfate concentration varied from 1262 mg/L to 22.95 mg/L and 5102 mg/L to 130.61 mg/L in phase-I and phase-II, respectively. All samples were in normal range except four samples and two samples from Manchar Lake in phase-I and half (10) samples from phase-II. Elevated consumption of SO_4^{2-} may cause diarrhea, catharsis, and gastro-intestinal effects.

Chemical parameters

Magnesium

Magnesium in water occurs as salts of magnesium. It contributes to the hardness of water together with calcium. According to WHO, the permissible limit of magnesium in drinking water is 150 mg/L [29]. The maximum Mg concentration was 160.75 mg/L and 174.96 mg/L in phase-I and phase-II samples and minimum Mg concentration was 4.86 mg/L and 12.15 mg/L in phase-I and phase-II samples, respectively (Table 3). A total of 18 samples of phase-I and 16 samples of phase-II were within the normal range. Only small number of samples were found containing high magnesium and these results were consistent with studies reported previously [30]. High concentration of Mg^{+2} may cause a laxative effect and its salts are cathartic and diuretic, while deficiency may cause functional changes as it's an activator of several enzymes.

Chloride

Chloride (Cl^{-}) is major inorganic components, which may destroy the quality of water for drinking purpose if present in elevated concentration. The chloride is present in water in combination with sodium, magnesium, and calcium. Chloride observed under the normal range (WHO normal limit is 250 mg/L) in all samples except four samples of phase-I and eight samples of phase-II (Table 3). The chloride concentration ranged from 1302 mg/L to 31.9 mg/L and 1169.8 mg/L to 187.8 mg/L in samples of phase-I and phase-II, respectively. Elevated chloride level increases corrosion of pipes and this can lead to increased concentration of metals in the water supply. Increased consumption of Cl^- rich drinking water

Table 3 Physical and chemical analysis results of water samples.

Samples	EC (µS/cm^3)		TDS (mg/L)		Salinity (ppt)		pH		Turbidity (NTU)		Alkalinity (mg/L)	
	Phase-I	Phase-II	Phase-I	Phase-II	Phase-I	Phase-II	Phase-I	Phase-II	Phase-I	Phase-II	Phase-I	Phase-II
Manchar	4980	3430	3187.2	2195.2	2.7	1.8	7.06	8.3	270	177	145	545
River Max	628	3530	401.93	2259	0.3	0.4	7.48	8.4	450	311	210	190
Mean	366.44	1314.85	698.39	2752.08	0.5	1094.82	19.923	15.814	120	157.12	177.5	367.5
Min	312	532	192	340	0.1	0.3	6.5	7.5	136	100	120	120
	Total-hardness mg/L		**Ca hardness (mg/L)**		**Mg (mg/L)**		**Cl (mg/L)**		**Ca (mg/L)**		**K (mg/L)**	
	Phase-I	Phase-II	Phase-I	Phase-II	Phase-I	Phase-II	Phase-I	Phase-II	Phase-I	Phase-II	Phase-I	Phase-II
Manchar	860	1000	370	300	119.07	170.1	1302	1047.7	148.29	120.24	48.4	45.4
River Max	850	1030	170	600	160.7	174.96	248.1	1169.8	68.13	240.8	15.6	43
Mean	1332.7	1806.14	836.59	1407.71	47.228	240.5	265.18	376.25	198.74	184.36	119.42	218.48
Min	190	450	90	150	4.86	12.15	31.9	187.8	36.07	60.12	3.2	2.7
	SO_4 (mg/L)		**Si (mg/L)**		**Co (ppb)**		**Ni (ppb)**		**Zn (ppb)**		**Cu (ppb)**	
	Phase-I	Phase-II	Phase-I	Phase-II	Phase-I	Phase-II	Phase-I	Phase-II	Phase-I	Phase-II	Phase-I	Phase-II
Manchar	1262	5102	2.34	8.87	302	355	257	214	3000	2644	320	0
River Max	234.6	816.3	49.54	22.7	258.7	355	296	811	1229	1347	1076	989
Mean	720.19	1533.78	244.35	404.184	105.66	186.844	351.78	544.86	688.03	670.93	243.23	202.65
Min	22.9	130.6	1.8	4.6	26	2.7	26	13.6	10	289	24	0.237
	Na (mg/L)		**Fe (ppb)**		**Mn (ppb)**		**As (ppb)**		**Cd (ppb)**			
	Phase-I	Phase-II	Phase-I	Phase-II	Phase-I	Phase-II	Phase-I	Phase-II	Phase-I	Phase-II		
Manchar	36	700	2410	2526	0	2767	10	25	0	353.8		
River Max	90	540	155	9674	0	4700	50	50	0	213.6		
Mean	365.1	1324.67	421.86	1827.19	99.603	1196.96	146.1	263.75	709.01	796.92		
Min	7.8	26	54	10	0	352	5	5	0	44.7		

may cause osteoporosis, renal stones, hypertension, risk for stroke and left ventricular hypertrophy [31].

Calcium

Calcium is the basic structural component of teeth, bone, and soft tissues and involved in many metabolic activities in the body. The WHO recommended value of calcium in drinking water is 100 mg/L. The calcium concentration was under the reference range except four samples of phase-II. The maximum and minimum calcium concentration observed was 240.48 mg/L and 60.12 mg/L in samples from phase-II (Table 3). Intake of heavy amounts of calcium, for short period, does not induce any adverse effects on the body; however, humans exposed to Ca for a long time may come across hypercalcemia, urinary tract calculi and calcification in soft tissues like kidneys and in arterial walls beside suppression of bone remodeling [32].

Potassium

Potassium is an essential element for humans and plays role in many enzymes. It is required for the secretion of insulin, creatinine phosphorylation, carbohydrate metabolism and protein synthesis. Potassium concentration found beyond the WHO range (12 mg/L) in four samples of Indus River and Manchar lake in phase-I and six samples of phase-II. The concentration of potassium in both phases ranged from 48.4 mg/L to 3.2 mg/L and 45.4 mg/L to 2.7 mg/L in phase-I and phase-II, respectively (Table 3). According to PCRWR, potassium concentration was exceeded in 36-46% of samples above the reference range from Faisalabad, Pakistan. The higher concentration of K ingestion may cause significant health effects in people with kidney disease or other conditions, such as heart disease, coronary artery disease, hypertension, diabetes and adrenal insufficiency.

Silicon

Silicon is dissolved in the form of silicic acid in drinking water. Silicon concentration above 9 mg/L is considered hazardous for health. In this study, 12 samples out of 20 in phase-I and 14 samples out of 20 in phase-II were observed above the reference range. The concentration of silicon ranged from 49.54 mg/L to 1.8 mg/L and 22.7 mg/L to 3.96 mg/L in water samples of phase I and phase II, respectively (Table 3). There is less data available on silicon water toxicity, may be due to lack of any observed toxicity and its toxicity related to overexposure needed to be explored. However, silica presence in drinking water could act as natural counteragent of the aluminum and could play a beneficial role in Alzheimer's disease by decreasing the biodisponibility of aluminum and preventing its toxicity associated with Alzheimer's disease [33].

Sodium

Sodium is naturally present in all water sources. The presence of sodium in water depends upon the anions and the temperature. The normal WHO limit for sodium is 200 mg/L. Sodium concentration was found normal in all samples of phase-I and phase-II except six samples of phase-II were above the WHO range (Table 3). The high concentration of sodium in drinking water changes the taste of water and makes it inappropriate for domestic use. Over exposure of sodium may cause cardiac, renal and circulatory diseases [34].

Arsenic

Arsenic is a carcinogen poses public health in many countries like Bangladesh, India, China, Vietnam, Nepal and Myanmar [35]. It occurs in water in the form of arsenite, arsenate, and organic arsenicals. The concentration of arsenic in drinking water of many regions of Pakistan exceeds the WHO standard of 10 ppb (µg/L). A study conducted previously reported that drinking water available to eleven cities of Punjab showed an excess of arsenic [36]. In a recent study, arsenic concentration of 96 µg/L in groundwater and 157 µg/L in surface water (Manchar Lake, Sindh) has been documented [37]. In this study, 10 samples of phase-I and eight samples of phase-II revealed elevated arsenic level above the normal range. The maximum concentration of arsenic was 50 ppb in both phases (Table 3). Overexposure to arsenic in drinking water causes several health issues including nausea, vomiting, lower white and red blood cells production, damage blood vessels, disrupt the heart rhythm and cause uncomfortable tingling in hands and feet [38]. Long-term exposure to arsenic can cause several kinds of melanosis and cancer [39].

Zinc

Zinc (Zn) is an essential element for humans and plays a beneficial role in normal growth and reproduction [40]. For drinking water, WHO set maximum acceptable concentrations of 3 mg/L. Zinc level found beyond the normal range in 6 samples of phase-I and all samples of phase-II. The concentration of zinc varied from 3000 ppb to 10 ppb and 2644 ppb to 289 ppb in samples of phase-I and phase-II, respectively (Table 3). In most cases, Zn concentration in drinking water is found within the normal range in Pakistan. A study conducted in Karachi showed a higher concentration of Zn (4.02 mg/L) [41]. However, another research reported Zn concentration in drinking water varied between 0.040 to 0.046 mg/L in pre-monsoon and post-monsoon seasons of district Thatta, Sindh [11].

Cadmium

Cadmium (Cd) has no positive role in health causing both acute and chronic problems in humans. The permissible range for Cd concentration in drinking water set by WHO is 0.003 mg/L. The concentration of Cd was observed within the safe limits in all samples of phase-I. However, Cd was detected in all samples of phase-II above the normal range. The maximum and minimum concentration of Cd was 353.8 ppb and 44.7 ppb, respectively (Table 3). Intake of Cd may cause acute gastrointestinal problems, such as nausea and diarrhea [42], while chronic exposure to Cd for a long time may cause kidney damage [43], reproductive problems [44], bone damage [45] and cancer [46].

Manganese

Manganese (Mn) is a normal constituent of human diet and poses a small problem in some parts of Pakistan where it exceeds the WHO standard limits (0.5 mg/L). The concentration of Mn was below the detection limit in all samples of phase-I and half samples (10) of phase-II. The maximum concentration of Mn was 4700 ppb (Table 3). A study conducted previously showed that the concentration of Mn (2.56 mg/L) was high in groundwater samples of Khyber Pakhtoonkhwa [47] and water samples (1.06 mg/L) of Faisalabad [48]. Over exposure of Mn through drinking water causes permanent neurological disorders similar in symptoms to idiopathic Parkinson disease [49].

Iron

Iron (Fe) is an essential element for the normal physiology of humans and its deficiency and overexposure can cause severe health problems. In drinking water, the permissible limit of Iron set by WHO is 0.3 mg/L. A study conducted in Pakistan reported that Fe concentration was overloaded in 28% of ground water samples and 40% of surface water samples [36]. The level of iron observed above the reference range in samples of both phases. However, the concentration of iron was much higher in phase-II than Phase-I. The iron concentration ranged from 155 ppb to 54 ppb and 9674 ppb to 10 ppb in samples of phase-I and phase-II, respectively (Table 3). Manchar samples revealed the iron concentration of 2410 mg/L and 2526 mg/L in samples of phase-I and phase-II.

Table 4 Chronic health quotient (HQ) values of adults and children for different metals.

Metal ions	Chronic HQ Adults				Chronic HQ Children			
	Phase I		Phase II		Phase I		Phase II	
	Body weight 70 kg				Body weight 15 kg			
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
As	9.52E-01	2.38E+01	4.76E-01	4.76E+00	1.22E+01	6.11E+01	1.22E+00	6.11E+00
Co	8.95E-01	4.14E+00	8.48E-01	2.77E+00	6.36E-01	3.69E+00	7.82E-01	8.68E+00
Ni	0.00E+00	4.14E-02	5.71E-02	1.73E+00	9.53E-02	0.00E+00	8.58E-01	4.45E+00
Zn	9.52E-04	1.05E-03	7.99E-02	1.14E-01	9.53E-03	1.22E-03	9.70E-02	1.21E-01
Cd	0.00E+00	0.00E+00	2.29E+00	2.02E+01	0.00E+00	0.00E+00	5.87E+00	5.19E+01
Cu	6.86E-02	0.00E+00	9.03E-02	0.00E+00	1.76E-01	0.00E+00	6.31E-02	1.26E-01
Mn	0.00E+00	0.00E+00	5.03E-01	4.29E+00	0.00E+00	0.00E+00	1.29E+00	3.19E+01
Fe	2.52E+01	1.10E+03	2.31E+01	3.00E+02	6.89E-02	1.04E+00	2.31E+01	3.00E+02

Table 5 Dermal health quotient (HQ) values of adults and children for different metals.

Metals	Dermal HQ Adults				Dermal HQ Children			
	Phase I		Phase II		Phase I		Phase II	
	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
Cu	1.34E-05	2.98E-07	1.23E-05	9.20E-07	3.95E-05	8.80E-07	1.16E-05	9.53E-06
Cd	0.00E+00	0.00E+00	1.08E-03	7.33E-04	0.00E+00	0.00E+00	1.03E-02	5.99E-03
As	1.82E-03	9.09E-04	1.82E-03	9.09E-04	1.07E-03	5.37E-03	2.68E-03	5.37E-04
Mn	1.33E-05	2.98E-07	5.16E-04	9.19E-07	0.00E+00	0.00E+00	1.52E-03	6.28E-04
Ni	1.27E-06	3.20E-07	2.36E-06	1.50E-07	1.71E-05	9.45E-07	1.04E-05	4.43E-07
Zn	1.93E-05	5.81E-05	1.04E-03	7.41E-04	1.37E-03	6.16E-05	1.16E-02	5.93E-03
Fe	7.78E-06	5.13E-07	1.06E-06	3.31E-08	2.30E-05	7.82E-07	2.47E-05	9.78E-08

Iron overexposure is a less common condition in comparison to its deficiency, but it can lead to several serious health problems like cancer [50], diabetes [51], liver and heart diseases [52] as well as neurodegenerative disorders [53].

Cobalt

Cobalt is relatively low in drinking water. It stimulates the production of red blood cells thus, used to treat anemia in pregnant women. Cobalt level was observed below the normal range in the water samples of both phases (Table 3). So the water samples of both phases were suitable for drinking purpose with respect to cobalt contents.

Nickel

Nickel (Ni) is known to be a carcinogen to humans. The maximum admissible concentration set by WHO for nickel in drinking water is 0.02 mg/L. The concentration of Nickel was above the normal range in 10 samples of phase-I and all samples of phase-II. The maximum and minimum concentration of Nickel was 296 ppb and 811 ppb, and 26 ppb and 13.6 ppb in samples of phase-I and phase-II, respectively (Table 3). The high concentration of nickel is reported in ground water samples from Karachi (0.01–2.19 mg/L) and 75% of surface water samples from Karachi exceeded the US EPA limit for Nickel [49]. Nickel causes variety of adverse health effects, including dermatitis, cardiovascular diseases, lung fibrosis, kidney problems and cancer of the respiratory tract [54-56]

Copper

Copper is one of the essential elements for life and it plays an important role in many enzymatic reactions and respiratory pigments. The normal WHO limit for copper is 1 mg/L. The copper concentration ranged from 1076 ppb to 24 ppb and 989 ppb to 0.237 ppb in samples of phase-I and phase-II, respectively. Only six samples of phase-I were above the normal range and except six samples of phase-II, all were beyond the reference range (Table 3). The high concentration of copper in water could cause epigastric burning, vomiting and diarrhea [57]. Accumulation of copper in the animal body in excess amount is toxic and in human may lead to hepatic cirrhosis and hemolytic anemia [58].

Microbial contamination

Coliforms were found positive in all samples irrespective to the collection point. It may cause dysentery in less immune adults and infants as local communities were taking water directly from the source for drinking purpose. As per of data collected from the hospital, the major disease ratio was dysentery especially in infants and became a serious issue in the dry season (phase-II) because of unavailability of fresh water from the upper stream of river and communities were using stagnant water for drinking purpose for survival. Microbial contamination of drinking water is a major cause of water-borne disease like vomiting, diarrhea, typhoid, dysentery and other health problems, especially in children and individuals with weak immunity [36, 59].

Health risk assessment

Carcinogenic health quotients of arsenic were observed under the normal level in all the samples as per formula for 15 kg weight and 70 kg weight, except for two to three samples that reflect the hypothetical non-carcinogenic impact of arsenic in drinking water of river Indus (Table 4). Health impact of metals has been found more serious during the post-flood condition than during the flood. HQ chronic (oral) of arsenic and iron observed insignificant in 50% of samples for 70 kg and all samples found insignificant for 15 kg. HQ of cadmium identified normal in phase-I, but insignificant in phase-II for both 70kg and 15 kg. For cobalt, maximum values were found for both 70 kg and 15 Kg. For Nickel, HQ was observed significant in phase-I and vice versa. The HQ of zinc and copper was found in a significant range in both phases of 15 kg and 70 kg weight.

HQ dermal of both phases (all water sources) with respect to different metals found within the normal range (HQ<1). However, HQ for adults was found closer to unity, but within the limit and HQ for children revealed future alarm (Table 5). As reported in previous studies that local residents in Karachi, Pakistan, and Nanjing, China might be exposed to minimum health hazards due to metal contaminants (HQ dermal<1) in drinking water. The results in this study found to be consistent with the study reported previously in Johi sub-division of Sindh [60].

Conclusions

The overall situation of heavy metals in phase-I and phase-II shows a large variation in their contamination level and frequency. Phase wise variation reflected that heavy metals of phase-II water samples (post flood) were observed worse than phase-I (during the flood). All heavy metals except cobalt have their concentrations beyond the reference range in many cases. The elevated contamination of heavy metals in drinking water is linked to severe public health problems. In Sindh, Pakistan, local authorities merely implement policies set by the federal government. The problem lies in the absence of a body or a mechanism to coordinate the tasks of the organizations responsible for water management during disasters. Thus, there was no improvement carried during and after the flood in this province to provide safe drinking water and to protect affected communities. This research work provokes concerns about the quality of water during and after the flood in affected areas of Manchar and adjoining areas. This study revealed that physical (except turbidity), as well as chemical parameters of drinking water after the flood (phase-II), were above the reference range and higher than during flood (phase-I). Bacterial contamination was found highly positive in both phases which is threatening situation especially for infants. HQ (carcinogenic) of arsenic of all the samples was below the normal range irrespective of 70 kg or 15 kg body weight. HQ chronic of arsenic and iron observed insignificant in all samples of 15 kg and half samples of 70 kg. HQ chronic of cadmium and Nickel observed insignificant in phase-II for both weights. High values of HQ chronic of cobalt observed in samples of both phases for both 70 kg and 15 Kg. HQ dermal was observed within the normal range for children as well as for adults. There is a clear variation of contamination burden in both phases and more health concerns were observed in phase-II samples that might be due to less flow of water in Indus River and low dilution of contaminants. Thus, the population in these areas was the victims of health problems associated with heavy metals toxicity and microbial contamination. It's suggested here that proper regulation of water during the flood and after the flood should be carried out in order to keep the communities safe from water borne diseases.

Conflict of interest

The authors declare that they have no conflict of interest.

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