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Impacts of seasonal variations on water quality, waterborne diseases, and related health risks

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ABSTRACT

Seasonal variations have great impact on water quality, waterborne diseases (WBD), and related health risks. In this study, effects of seasonal variations on physicochemical parameters like pH, temperature, electrical conductivity, dissolved oxygen (DO), waterborne bacteria (total coliform and faecal coliform) and related risks on human health were analyzed in Rawalpindi and Islamabad cities by using standard methods of chemical and microbiological analysis. Results were correlated with seasonal parameters (temperature, rainfall, etc.), and also showed that all the drinking water samples were found tasteless, colorless, and odorless. Other quality parameters were found within the recommended limits of the WHO guideline. However, significant decrease in DO level in the drinking water samples was found below the recommended level of WHO guidelines. Similarly, bacterial growth was found varied in the different months and with the changing season pattern. No growth of *Legionella* spp. or *V. cholera* was found from the analyzed samples. Health risks survey showed that residents of the study area were using different means of water sources like water filtration plants, water supply, borewells, etc. People have good perception about water quality (83%). Majority of the residents (72%) were not satisfied about the water quality in Rawalpindi city as compared to Islamabad but the same number reported no regular monitoring of water quality. About 98% were familiar with the WBD and 93% educate their children about WBD. No separate record for WBD had been found in the hospitals to correlate the data with the diseases spread in the different seasons. It is suggested to maintain the separate record for WBD to correlate with the seasons along with regular monitoring of drinking water sources and check the sewerage contamination to avoid the risk of WBD.

Keywords: Health impacts; Seasonal variations; Waterborne bacteria; Water quality; Water supply

1. Introduction

Water is extremely essential for survival of all living organisms. The quality of water is vital concern for mankind since it is directly linked with human welfare [1]. The groundwater is believed to be comparatively much better and free from pollution than surface water. But prolonged discharge of industrial effluents, domestic sewage and solid waste dump causes the groundwater to become contaminated and created health problems [2]. Aquatic pathogens of animal and human faecal origin may include

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bacteria, viruses, and parasites. Also, some naturally occurring microbes can become pathogenic, e.g., species of *Vibrio* (septicemia, diarrhea, and gastroenteritis), amoebae (encephalitis), *Pseudomonas aeruginosa* (infection of ear and skin), and *Legionella pneumophila* (Legionnaires' disease) [3]. Some bacteriological pathogens can reproduce without specific host under favorable environmental circumstances [4].

Heavy rainfall leading to floods will ultimately cause higher pathogen concentration in the naturally available water sources which will usually be mirrored in the worsening of quality of bathing and drinking water. Indeed, heavy floods/rainfall can also cause overflowing of sewage handling plants, runoff of animal manure, redistribution, and remobilization of polluted sediments [2,6,7]. Studies on *Cryptosporidiosis* propose that in future additional intense precipitation events may exaggerate the overload of soil profiles and mobilize infectious oocysts more frequently leading to significant increase of the risk [8].

Groundwater quality in different seasons have been monitored in North West China to assess the suitability for irrigation and human consumption but the water samples were found contaminated and unfit for both uses and slight improvements in quality parameters during monsoon [9] as rainwater dilute the contaminants. Gastroenteric pathogens in the marine environment are normally deactivated by higher temperatures, however, their sensitivity shows dissimilar features. For example, *Enteroviruses* and *Giardia* cysts are less quickly inactivated compared with oocysts of *Cryptosporidium* [10]. *Cryptosporidium* oocysts can become deactivated in the winter, as they are vulnerable to freezing and melting cycles [8]. Moreover, it is also predicted that the rise in the temperature of aquatic environment is dangerous with respect to cholera disease (survive in higher temperatures) in Asia and South America [5]. Despite much progress in the understanding of the pathogenesis and the management, diarrheal illness remains one of the most important causes of global childhood mortality and morbidity, this is largely because the etiology and pathogenesis of persistent diarrhea which are usually multifactorial and sometimes cannot be identified [11].

There are numerous cases of waterborne disease outbreaks related to extreme rainfall [9,12]. The largest waterborne disease outbreak reported was in the United States, happened in Milwaukee lake in 1993 caused by the incidence of *Cryptosporidium* cysts in the drinking water, resulted in 403,000 illnesses and 54 deaths [10,13]. There are reports on outbreaks of other diseases due to the pollution in groundwater after flooding, e.g., an outbreak of giardiasis in Montana (USA) was related to excess rainfall [14] and *Acanthamoeba keratitis* in Iowa (USA) [5]. Cryptosporidiosis cases in England and Wales were positively associated with maximum river flow [15]. Curriero et al. [16] stated a substantial association between outbreaks of waterborne disease and excess rainfall. This study analyzed 548 already reported outbreaks in the United States from 1948 to 1994. The results showed that almost 51% of outbreaks were preceded by heavy rainfall [16]. Failure of sewage treatment plant due to heavy rainfall caused worldwide outbreak gastroenteritis due to ingesting of oysters picked from Tahu lagoon, in France [17,18]. Other imperative outbreaks related to polluted oyster/clam ingesting caused by sewage run-off and release into the aquatic environment during heavy rainfall were also testified which affected more than 2,000 people in Australia, in summer 1978 [19], and 1,000 people in New York State in 1982 [20].

A systematic analysis on *Vibrio* spp. and *Leptospira* spp., followed by *E. coli*, identified these microbes as commonly found pathogens in the outbreaks of waterborne diseases (WBD) after flooding, mostly in Asia [24–26]. There was a significant rise in diarrheal diseases among young children and the elderly people after 2007 flooding in China [21]. An about 21,401 cases of diarrhea were treated in the hospitals of Bangladesh in August 2007, due to severe flooding [22]. In 2010, diarrhea was a principal reason of illness in Pakistan due to flooding accounting for more than 17% of medical sessions in the worst affected area [23]. Present study was conducted to assess the impact of seasonal variations on water quality and WBD in Rawalpindi/Islamabad region of Pakistan with special emphasis on to assess the impacts of temperature, precipitation, change in rainfall pattern on water quality and to compare the impacts on bacterial diseases especially during monsoon and dry weather.

2. Methodology

2.1. Description of study area

Both Rawalpindi and Islamabad cities were focused during the study. Rawalpindi city, Punjab province, Pakistan was the capital of Pakistan from 1959 to 1969. The city lies on the Pothwar Plateau 9 miles (14 km) southwest of Islamabad, the national capital. The Lehi River separates the city from the cantonment (permanent military station), and a satellite town has been built on the Murree Road. The nearby Rawal Dam, on the Kurang River, completed in 1961–1962, provides Rawalpindi and Islamabad with water. Similarly, Islamabad is the capital city of Pakistan with an estimated population of 1.74 million in 2009. The Rawalpindi/Islamabad Metropolitan Area is the third largest in Pakistan, with a population of over 4.5 million inhabitants. Islamabad is in the Pothwar Region in the North of Pakistan. The city was built during the 1960s to replace Karachi as Pakistan's capital. Compared to other cities of the country, Islamabad is a clean, spacious and quiet city with lots of greeneries.

The seasonal and precipitation variations of Rawalpindi and Islamabad are quite similar to each other. In terms of temperature both the cities exhibit abrupt fluctuation probably associated with urbanization (Rawalpindi) and vegetation cover (Islamabad). The maximum and minimum temperature varies between –2°C and 45°C, respectively [24]. The mean annual evaporation was 1,283 mm [25]. Regionally, the mainstream of the area is Soan and along with its tributaries such as Ling, Gumrah Kas, Korang, and Lehi Nullah supply water to different catchments. Three dams, Simly, Khanpur, and Rawal dams with mean annual storage capacity of 68, 198, and 72 million gal/d, respectively, are supplying water to both the cities [26]. In addition to that both the cities depend upon groundwater that is supplied by 180 tubewells (Capital Development Authority) in Islamabad about 260 tubewells (Rawalpindi

Development Authority) to Rawalpindi [27]. In addition to the several domestic wells also supply water to the residents of both the cities [25]. The major formations of the area are the recent Lehi conglomerates, Soan formation under lain by Murree formation [26]. Ahmad et al. [28] studied the hydrogeological framework of both the cities; identified multiple aquifer systems overlain by silt and clay. The shallow aquifer system comprised of fluvial sediments often deposited by the stream dominated by sand, gravels, and conglomerates whereas deeper aquifer systems at some locations comprised of sandstone of Murree formation.

2.2. Sample collection and preservation

Samples were collected from the twin cities of Rawalpindi (Dhoke Syedan, Misrial Road, Chour Chowk, Friends Colony, Officers Colony, PIA Colony, Chakra Road, and Sayyam Road) and Islamabad (G-9, G10, and F8 sectors). A total of 192 samples (in triplicates) were collected from 16 locations (8 from each city) on monthly basis during November 2018 to October 2019 that include borewells, tubewells, and households (Fig. 1). Data regarding meteorological parameters were also collected during the study period to correlate the water quality parameters and waterborne bacteria. All the samples were collected according to the guidelines recommended by Standard Methods for Examination of Water and Wastewater [29] and Manual of Clinical Microbiology [30]. Two to three drops of 3% sodium thiosulfate solution were added to the bottles before sterilization for neutralizing the bactericidal effects of any chlorine content present in the samples. The sample bottles were preserved in a sampling basket fitted with ice to limit bacterial growth at 4°C and was carried to the laboratory for analysis within 4–5 h after collection.

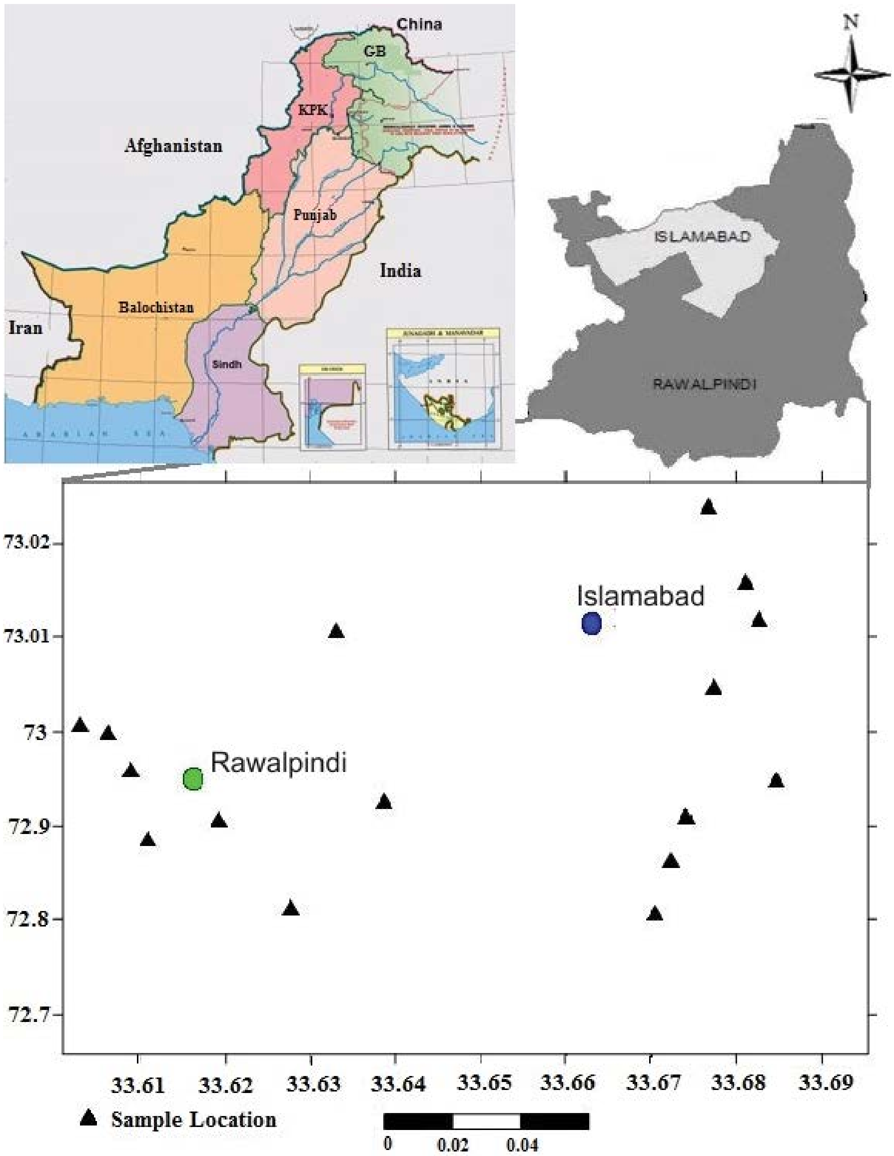

Fig. 1. Geographic Information System map of sampling from Rawalpindi and Islamabad (adapted from [31]).

2.3. Analytical procedure for analysis

All the chemicals and equipment used in the analysis were of lab grade purchased from E. Merck and Scientific Enterprise. In order to assess the impacts of seasonal variation and climatic parameters especially during monsoon and dry weather, water samples were analyzed for physicochemical parameters like taste, color, odor, temperature, pH, electrical conductivity (EC), total dissolved solids (TDS), dissolved oxygen (DO), and the presence of waterborne bacteria according to the standard methods [29,30]. Readings were recorded through a calibrated combo meter (HANNA, HI 98129). The pH of the water samples was measured with a calibrated pH meter (Eutech, Eco Testr pH 1). Waterborne bacterial species were isolated and identified according to the standard microbiological methods [30]. The bacteriological quality analysis of water samples was conducted by Membrane Filtration Method [29] along with control. Identification of strains was performed through standard methods [29,30]. Pure culture was obtained using streak plate method and morphology of strains was determined by Gram staining technique. Analytical profile index for *Enterobacteriaceae* through biochemical tests.

2.4. Prevalence of diseases/health impact study

A water quality survey questionnaire was developed to obtain information related to water quality, water availability and health risks associated with water, from the inhabitants of the study area (n = 60). The health questionnaire aimed at assessing the prevalence of different water-related diseases. Data were correlated with the information obtained from the public and allied hospitals in the study areas and the prevalence of disease was assessed through pre-designed questionnaire.

2.5. Climate impacts on water quality and waterborne bacteria

Meteorological data of the study period were obtained from Pakistan Meteorological Department (PMD), Government of Pakistan and correlated with the water quality parameters to assess the impacts of weather conditions on the study parameters.

3. Results and discussion

3.1. Physiochemical analysis

Physicochemical analysis of drinking water plays a vital role in demarcating water quality. These calculations give an interaction between different factors that contribute to changing water chemistry [31,32]. No change in aesthetic parameters was observed, all the samples collected were found colorless, tasteless, and odorless. pH is used to express the intensity of the acid or alkaline condition of a solution. Results showed that the pH values of water samples varied between 7.33 to 7.85 and 7.18 to 7.55 throughout the year in Islamabad and Rawalpindi, respectively. Only minor fluctuation in pH was recorded and found within the limit recommended by the WHO. Throughout the sampling period the value of pH in Rawalpindi city fluctuated between 7.1 and 8.0 at all 8 locations, whereas at location 1 in the month of January, maximum pH was recorded 8.0, while minimum pH had been recorded 7.1 at several locations. Whereas in Islamabad city the range of pH recorded was 7.1–7.9 at 8 selected locations, maximum pH was at location (6) in month of December while minimum pH was 7.1 at several locations. According to analysis, all the samples were within permissible limits for drinking water recommended by WHO. Quality of drinking water is affected due to increase in pH. Usually, pH increase in drinking water occurs due to wet season or rainy season and due to increase in temperature. Months that usually receive excessive amount of rainfall will have increase in pH concentration in drinking water. Generally, the pH concentration increases because of the photosynthetic algal activities that consumes carbon dioxide dissolved in water [33].

EC signifies the amount of total dissolved salts [34]. The range for EC values was 405–888 µs/cm and 475–730 µs/cm in Rawalpindi and Islamabad groundwater, respectively. High EC was observed in all the samples of Rawalpindi during the year in comparison with Islamabad samples except in the months of June, September, and October. The higher EC represents higher TDS, but EC also increases because of high anions present in the water. The EC in Rawalpindi water throughout the year indicated the dissolution of major anions in the water which generally comes from both geological and anthropogenic sources. Wastewater seeping, industrial and domestic waste infiltration could cause this increase in EC. The low concentration of EC in water samples of Islamabad throughout the year indicates good quality of water as compared to Rawalpindi. This is just because of precipitation rate in Islamabad which recharges the groundwater more frequently than Rawalpindi. All the EC values found in Rawalpindi and Islamabad groundwater are within the range recommended by WHO (Table 1). Similarly, the range of EC in drinking water in Rawalpindi city was 140–1,310 µs/cm at all selected locations, however, high EC was observed in location (1) in April 1,310 µs/cm while minimum was 140 µs/cm in July at location (6). Whereas at sampling conducted at Islamabad city range of EC recorded was 140–1,180 µs/cm, high concentration of EC was observed in location (1) in June 1,310 µs/cm while minimum was 160 µs/cm in July at location (6) as shown in Supplementary Data.

TDS indicate the salinity behavior of groundwater. Water containing more than 500 mg/L of TDS is not considered as desirable for drinking water supplies, but in unavoidable cases 1,000 mg/L is also allowed [35]. The TDS concentration is considered as a secondary drinking water standard, which means that it is not a health hazard. However, water with a high TDS concentration may indicate elevated levels of ions that do pose a health concern, such as aluminum, arsenic, copper, lead, nitrate, and other related issues. TDS values varied from 302 to 478 ppm and 293 to 508 ppm in Rawalpindi and Islamabad groundwater, respectively (Table 1). All the water samples showed the TDS values within the permissible limit throughout the year. However, the groundwater of Rawalpindi in the first 5 months showed very high TDS that was near to 500 mg/L whereas in the month of October the groundwater of Islamabad crossed the permissible limit with very few points. This increase in TDS in only 1 month

Table 1
Variations in physicochemical properties of in Rawalpindi and Islamabad throughout the year (Supplementary Data have been placed for detail)

Factor	City	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	WHO limits
		Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	
pH	Rwp	7.5 ± 0.14	7.4 ± 0.12	7.5 ± 0.18	7.4 ± 0.22	7.5 ± 0.19	7.51 ± 0.1	7.58 ± 0.1	7.67 ± 0.1	7.77 ± 0.1	7.85 ± 0.1	7.33 ± 0	7.7 ± 0.20	6.5–8.5
	Isb	7.37 ± 0.2	7.27 ± 0.1	7.18 ± 0.2	7.41 ± 0.2	7.46 ± 0.2	7.52 ± 0.1	7.58 ± 0.1	7.67 ± 0.1	7.75 ± 0.1	7.50 ± 0	7.56 ± 0.2	7.53 ± 0.2	
Temperature (°C)	Rwp	23.3 ± 0.4	20.7 ± 0.4	24.1 ± 0.2	27.2 ± 0.2	27.2 ± 0.2	27.2 ± 0.2	27.6 ± 0.2	28.0 ± 0.2	28.4 ± 0.2	23.5 ± 1.8	20.9 ± 1.4	20.5 ± 0.2	28–40°C
	Isb	24.3 ± 1.0	20.1 ± 0.2	24.9 ± 1.7	26.4 ± 0.1	26.4 ± 0.1	27.2 ± 0.2	27.1 ± 0.3	27.4 ± 0.1	28.3 ± 0.6	20.9 ± 0.6	20.4 ± 0	18.7 ± 0	
EC (µs/cm)	Rwp	766 ± 262	796 ± 172	863 ± 295	888 ± 302	810 ± 295	711 ± 295	611 ± 295	537 ± 256	461 ± 231	405 ± 246	787 ± 336	806 ± 385	1334
	Isb	657 ± 87	678 ± 90	655 ± 151	639 ± 152	543 ± 187	730 ± 280	593 ± 270	537 ± 256	475 ± 190	699 ± 108	619 ± 122	573 ± 154	µs/cm
TDS (ppm)	Rwp	478 ± 166	474 ± 77	433 ± 143	442 ± 173	416 ± 165	394 ± 164	374 ± 164	359 ± 155	351 ± 159	330 ± 136	302 ± 130	323 ± 104	1000 ppm
	Isb	325 ± 41	338 ± 55	320 ± 76	313 ± 77	293 ± 75	408 ± 155	366 ± 169	377 ± 162	351 ± 159	508 ± 193	437 ± 237	305 ± 63	
DO (mg/L)	Rwp	6 ± 0.2	5 ± 0	5 ± 0	4 ± 0	3 ± 0	2 ± 0	3 ± 0	4 ± 0	4 ± 0	5 ± 0	6 ± 0	5 ± 0	6–8 mg/L
	Isb	6 ± 0.35	5.25 ± 0.2	4.3 ± 0.17	4.2 ± 0.13	3.3 ± 0.20	2.4 ± 0.27	3.4 ± 0.19	3.6 ± 0.19	3.8 ± 0.31	5.6 ± 0.47	5.8 ± 0.20	5.41 ± 0.1	

indicates some point source contamination which is related to anthropogenic activities. In comparison of TDS with EC it is quite clear that the EC is nearly 2 folds high than TDS in the groundwater of Rawalpindi during the months of January, February, March, April, May, November, and December. This indicates that among other contaminants dissolution of anion plays the major part in increasing the TDS of Rawalpindi groundwater which could be due to the less precipitation in Rawalpindi region. This indicates the effect of meteorological parameters on water quality (Table 1). The high values of TDS are associated with less rain which allows the concentration of solvents to increase, same is the case with the EC due to less rain the conductivity in the water is affected by the inorganic dissolved solids such as calcium, chloride, aluminum cations, nitrate, sulfate, iron, magnesium, and sodium. On the other hand, organic compounds such as oil, alcohol, phenol, and sugar that can influence the water conductivity [36].

The DO shows very uniform semi-cyclic pattern, where the highest concentration was observed in January and November and the lowest was observed in June in all the water samples of twin cities. The month with high DO values, such as January, February, March, October, November, and December, represent heavy contamination by organic matter. This happened due to precipitation blending with organic contaminants on the surface and infiltrate through the soil into the aquifer. Majority of the aquifers in Rawalpindi and Islamabad are unconfined aquifer which is more vulnerable to organic contamination. In addition to that there are high chances of sewerage waste mixing in the groundwater through direct infiltration from cracks and buried leaked underground sewerage tanks or wells or may be from small landfill sites located in different parts of the twin cities.

The results of analysis indicated a direct relationship between the physiochemical parameters and seasonal variations. All the values were within the permissible limits recommended by WHO. The high values of temperature, DO, EC, and TDS correspond to dry seasons with low or no rain whereas the low values of these parameters represent the wet seasons with excessive rains (Table 1). High risk of cancer has been reported from consumption of tap water in wet season while high risk of cancer from consuming chlorinated water in dry weather [37] indicate a direct relationship in seasonal variation and their impacts on water quality.

3.2. Biological analysis

According to WHO standards permissible limit for drinking water for total coliform is zero CFU/mL and drinking water should be totally free from total and fecal coliform. Results of biological analysis showed that 50% of samples collected from all 16 selected locations from Rawalpindi and Islamabad were free from contamination and fall within the recommended limits of WHO for drinking water. It was observed that concentration of total coliform increased due to seasonal variation in 50% of the samples. Samples collected from location 1, 6, 7, 8 contained total and fecal coliform throughout the year, but the concentration increased during wet season and were not according to the recommended limits of WHO (Figs. 2 and 3).

Shar et al. [38] conducted a study to assess the bacteriological quality in 768 drinking water samples which

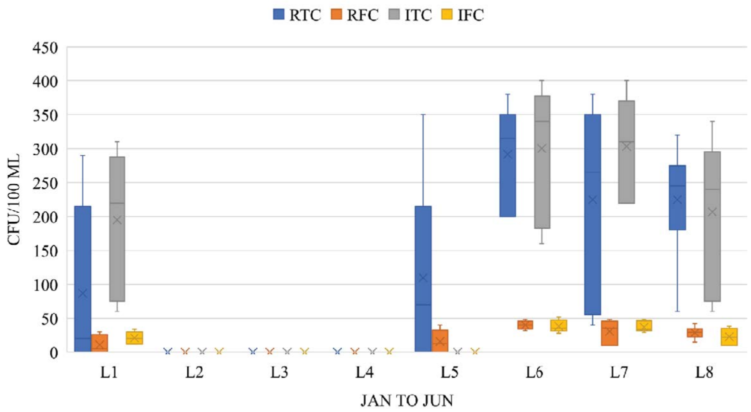

Fig. 2. Total and faecal coliform (CFU/100 mL) in the samples collected between January and June from all the locations.

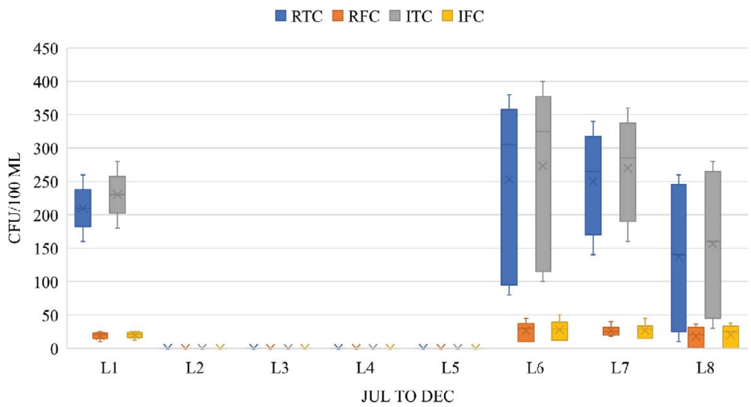

Fig. 3. Total and faecal coliform (CFU/100 mL) in the samples collected between July and December from all the locations.

were collected from different locations in Khairpur City, Sindh, Pakistan over a period of 2 y from January 2006 to December 2007. The study reveals that out of 768 drinking water samples 567 (73.83%) samples were found to be contaminated with total coliform among them 85 (11.06%) found in the January–March period, 182 (23.70%) in April–June period, 188 (24.47%) in July–September, and 112 (14.58%) in October–December period. Faecal coliform was found in 351 (45.70%) water samples, in which 49 (15.80%) occurred during January–March, 137 (17.83%) during April–June, 136 (17.71%) during July–September, and 69 (8.98%) during September–December. In one of the hospitals in Islamabad, 81.8% of gastroenteritis patients were found during the month of June, 2010 [39], but proper record is maintained for WBD. Presence of bacteria like total coliform indicates the requirement of regulate monitoring, proper treatment, and policy recommendation for the faecal pollution control in the major cities [40].

3.3. Health risk study

According to the one of the objectives of this study, questionnaire proforma was developed to find out the health-related issues caused by WBD due to seasonal variation. The total number of (n = 60) questionnaires were distributed among the local residence of the study area that include questions based on water quality, water availability, and health risks associated with water.

3.3.1. Water availability

Results showed that in Islamabad, 25% (15) of the respondents were using borewell as their current water supply source while 30% (18) were using filtration plants provided by local government. On the other hand, majority of respondents (36%) were obtaining water supply from tubewells and only 8% (5) respondents were getting water from private water tankers for their usage (Fig. 4). This shows that water supply source is different in study area for respondents. Similarly, in Rawalpindi city, situation was similar except people were more dependent (30%) on water tankers which affects the quality of water and pay more money as compared to water supply by the local authority in terms of water utility.

In Rawalpindi city, majority of respondents in study area were receiving water supply for about 1 h/d that is 37 which is about 62%, while 14 which is almost about 23% have 2 h of water supply per day, and only 9 which is 15% have ½ h of water supply per day. In Islamabad city, most people (61.6%) are receiving water for 1 h duration. Hence, people were not satisfied with the supply duration (Fig. 5).

Results showed that 76.6% of respondents in Rawalpindi city were not satisfied about the duration of water supply in their area while only 23% of respondents are satisfied with the duration of water supply in the same area. This shows that water supply in study area was not fulfilling the demands of peoples in Rawalpindi city. Similarly, 50% people were not satisfied in Islamabad city (Fig. 6).

3.3.2. Water quality

Results showed that 83% of respondents know about the water quality and 17% of those respondents are unaware of water quality in Islamabad city. This shows that most of the people were aware about the water quality while 26% were not satisfied to the quality. In Rawalpindi city, 78% people had perception and know about the water quality and 22% were unaware while 72% were not satisfied about the quality of water supplied to them (Fig. 7). This shows that most of the people in Rawalpindi city were not satisfied with the quality of water in their area and the quality of water in Rawalpindi city was not good enough to use for drinking purpose. Hence, people reply on filtration plants or borewell to protect themselves from the WBD.

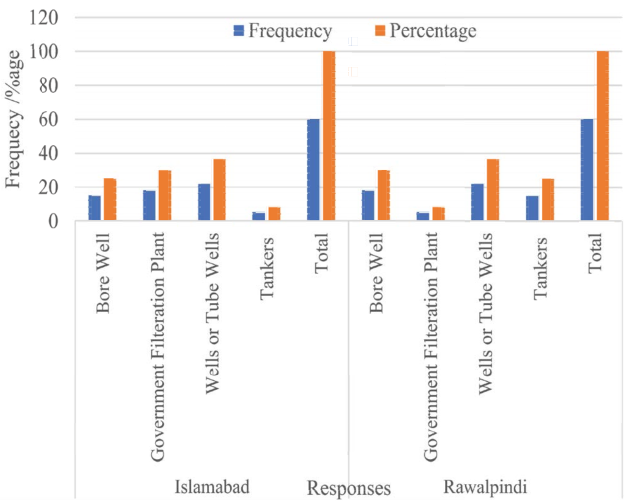

Fig. 4. Sources of water supply.

Similarly, 78% of the individual were using water treatment techniques at home for drinking water due to poor quality of water in Rawalpindi city and only 22% of respondents in study area were not using any water treatment techniques. Similarly, 88% people were using water treatment techniques at home for drinking water in homes like either they have installed water filtering or using boiled water.

About 50% of the people think that it is the responsibility of water authority or local government to maintain proper and good management of water quality, while 42% of the respondents think that it is the responsibility of both individuals and water authority for water quality management, and only 8% of people think that it is their responsibility. Regarding monitoring 72% of the respondents in study area said that there is no check or any sort of monitoring on water quality by water authority or local government in Rawalpindi city whereas only few people which is about 28% said that there are water authorities and local government for checking and monitoring water quality (Fig. 8). This shows that there is no regular monitoring of water quality. In Islamabad, 73% reported the monitoring of water quality in their area. It is predicted that water quality is monitored but not maintained the water supply which may be rusted or damaged with the passage of time.

3.3.3. Health risks

Results related to health risks showed that majority of respondents (90%) in Rawalpindi city were aware about WBD while only few (10%) were not familiar with the term waterborne disease. Similarly, in Islamabad, majority of respondents (95%) were aware about WBD while only few (5%) were not familiar with the term waterborne disease (Fig. 9).

Most of the individuals (98%) in Islamabad, not only know about WBD but also know about the relationship and linkage between water and diseases, and 97% in Rawalpindi city while only 3% were unaware about it. Similarly, 92% of the people in both cities believe that due to bad and poor management of water has led to different kinds of WBD and only 8% disagreed with the statement (Fig. 9).

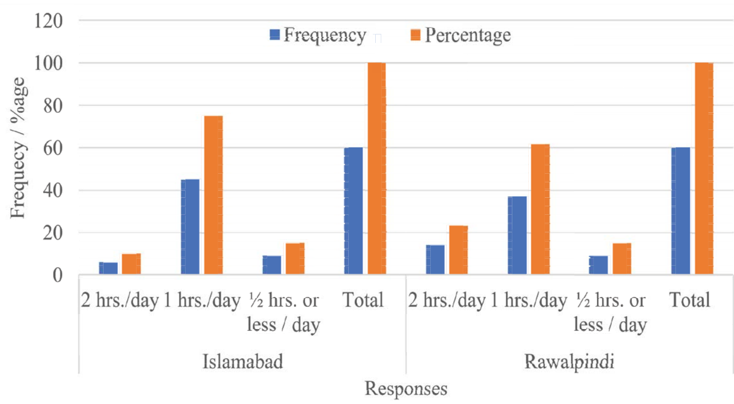

Fig. 5. Duration of water supply.

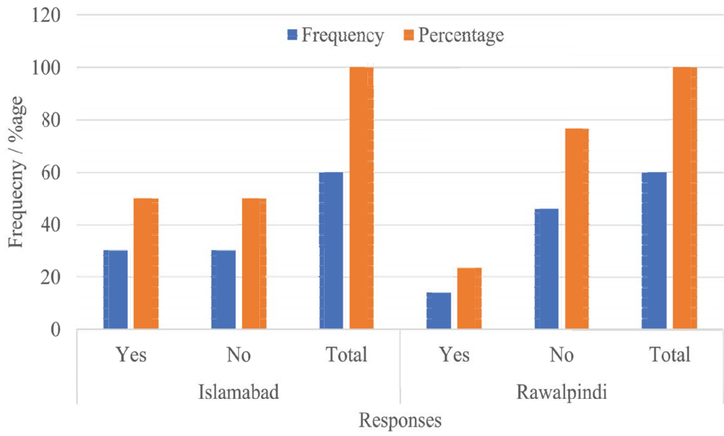

Fig. 6. Satisfaction about water supply duration.

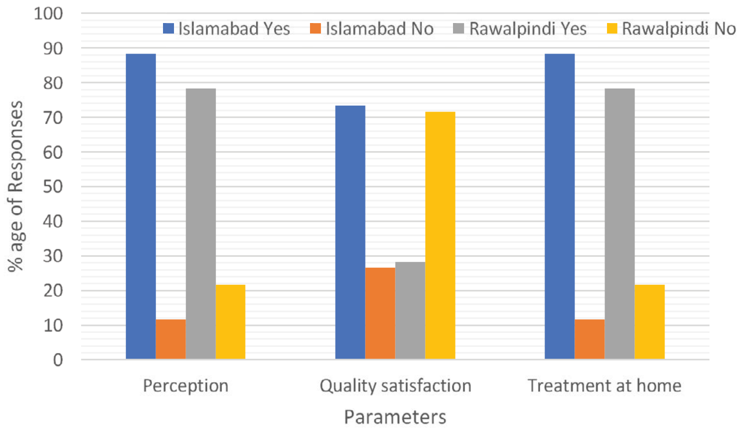

Fig. 7. Perception and satisfaction about water quality.

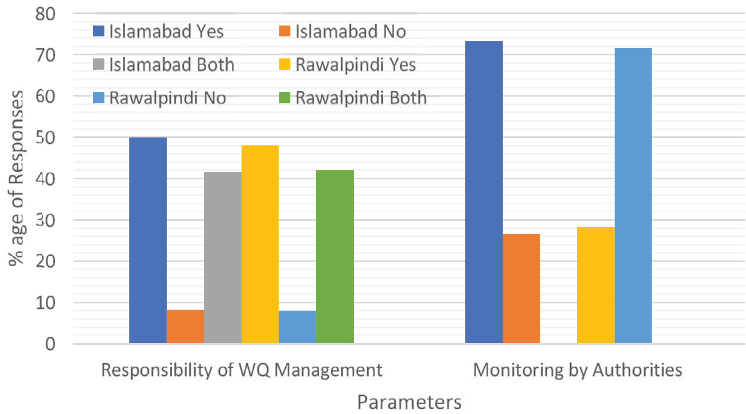

Fig. 8. Water quality management and monitoring responsibility.

Regarding educating children about WBD, 93% are the individuals who educate their children about WBD in Islamabad which is a good sign and 65% in Rawalpindi city, educate their children about WBD (Fig. 9). Accordingly, 91% and 81% have awareness about WBD in both the cities while more family members suffered in Rawalpindi city (88%) as compared to Islamabad city (75%). WBD are caused by contaminated water but awareness about the link with water quality is important.

During the study, it was observed that children (more than 50%) were more at risk to WBD as compared to other age group. This shows that all the individuals in study area are at risk to be affected by WBD but children are at most risk (Fig. 10).

3.4. Correlation between water quality, waterborne diseases, and climatic parameters

Climatic parameters like heavy rainfall and high temperatures have the potential to increase the risk of diarrheal diseases, one of the largest components of waterborne disease burden [41]. Similarly, another study reported that floods, droughts, heavy storms, changes in rain pattern, increase of temperature, and sea level, they all show an increasing trend worldwide and will affect biological, physical, and chemical components of water through different paths thus enhancing the risk of WBD [42]. Climate change is likely to increase diarrheal disease incidence worldwide, and extreme weather conditions may also complicate already-inadequate prevention efforts [43]. A study reported during June 2010, out of 220 individuals, 180 cases of gastroenteritis (81.8%) were recorded which were associated with poor drinking water [40]. Data obtained from Pakistan Meteorological Department (PMD), Government of Pakistan showed the increase in rainfall (mm) during July–August (during study period) and increase in temperature during June–July and decreasing trend had been observed after September. Minimum temperature was observed in February while highest temperature was observed in June (Fig. 11).

A Centre for Disease Control and Prevention study conducted found a relationship between temperature and waterborne illnesses. Number of reported cases of *Shigellosis* and *Giardiasis* appeared overall more as compared to other diseases [44]. Unfortunately, no relevant data have been found from the allied hospitals on waterborne infections in the study area. No data have been found especially on gastroenteritis or other waterborne infections as no record had been maintained separately for the waterborne infections in the hospitals. Despite several WBD like typhoid, gastroenteritis, shigellosis are reported in the newspapers.

A similar trend has been found with temperature as temperature may support the growth of bacteria but not statistically significant difference has been observed with rainfall. More comprehensive study is required to correlate the total and fecal coliform indicator bacteria with the meteorological parameters. Another study conducted on faecal indicator bacteria (FIB) reported no statistically significant difference in the FIB in the water samples from the river [45]. As increase in precipitation, change in rainfall temperature

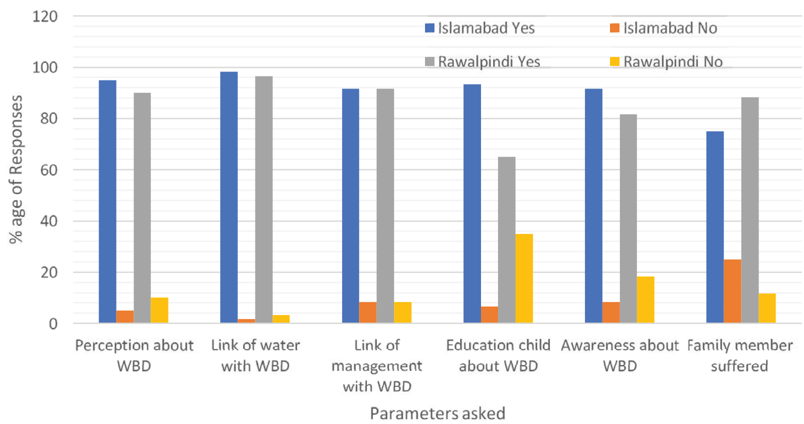

Fig. 9. Responses of the perception, linkage, management, awareness, educating children, and suffering from waterborne diseases.

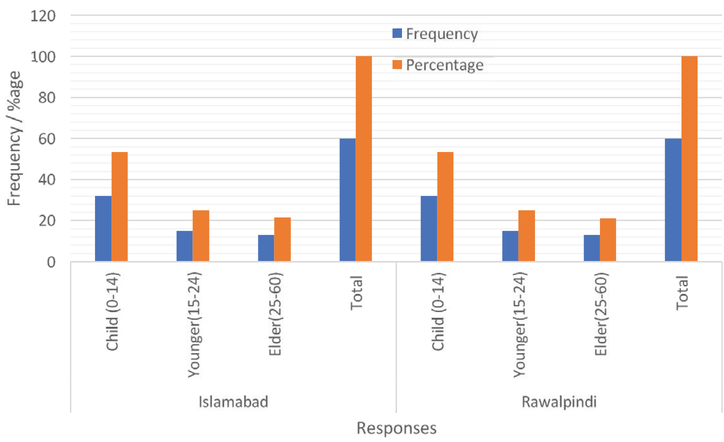

Fig. 10. Exposure to waterborne diseases.

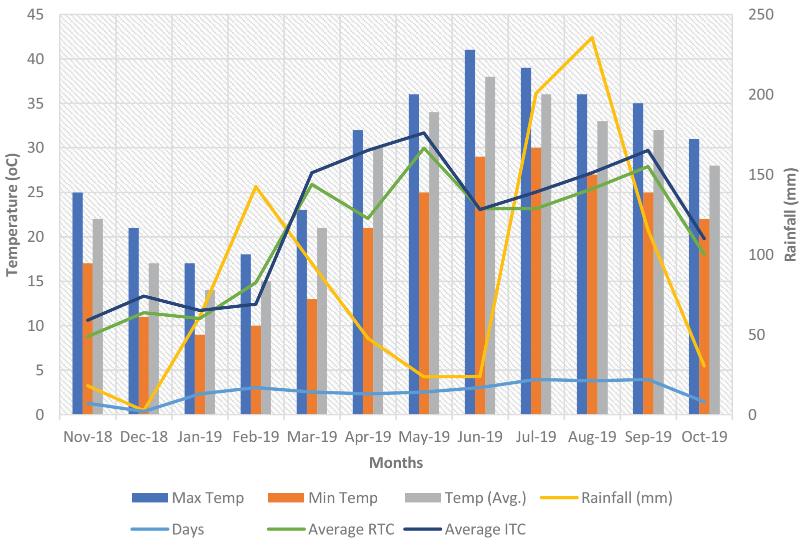

Fig. 11. Temperature and rainfall pattern with number of days during the study period (Nov 2018 to Oct 2019).

and increase in temperature highly impacts the growth of waterborne bacteria and parasites [46].

4. Conclusion

Water quality data were obtained through sampling and analysis. It was observed that total coliform and fecal coliform were increased during the monsoon period or wet period and a source was found contaminated and remained contaminated throughout the year which clearly indicated the persistent results and contamination of sources. Physicochemical parameters varied according to the seasons but fell within the permissible limit as recommended by WHO standards except DO level. Bacteriological parameters were found within the permissible limit except few sources. All the drinking water samples were found tasteless, colorless, and odorless. No growth of *Legionella* spp. or *V. cholera* was found from the samples analyzed. Only *E. coli* and *Pseudomonas* spp. have been identified in the samples analyzed. As per meteorological data, highest temperature was found during the month of June and July and rainfall was maximum during the month of July. If we correlate, the growth of bacteria during the wet months was found higher as compared to dry season. Similar results have been reported previously, as waterborne infections were high in July to September. Separate record for WBD had not been found in the hospitals of Rawalpindi and Islamabad to correlate the data with the diseases spread in the different seasons. It is suggested to maintain the separate record for WBD to correlate with the seasons along with regular monitoring of drinking water sources. It is highly recommended to conduct long-term comprehensive study on WBD/infections and to find correlation with meteorological parameters including modelling studies.

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Supporting information

Sampling sites	pH (Rawalpindi city)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Location (1)	8.0 ± 0.7	7.3 ± 0.7	7.3 ± 0.7	7.2 ± 0.2	7.3 ± 0.2	7.4 ± 0.2	7.5 ± 0.2	7.6 ± 0.2	7.7 ± 0.3	7.8 ± 0.4	7.1 ± 0.7	7.8 ± 0.1
Location (2)	7.8 ± 0.2	7.5 ± 0.7	7.9 ± 0.2	7.3 ± 0.7	7.4 ± 0.7	7.5 ± 0.07	7.6 ± 0.07	7.7 ± 0.5	7.8 ± 0.9	7.9 ± 0.5	7.6 ± 0.2	7.9 ± 0.2
Location (3)	7.4 ± 0.2	7.6 ± 0.3	7.7 ± 0.4	7.1 ± 0.1	7.2 ± 0.1	7.3 ± 0.1	7.4 ± 0.1	7.5 ± 0.1	7.6 ± 0.4	7.7 ± 0.3	7.1 ± 0.1	7.5 ± 0.3
Location (4)	7.5 ± 0.7	7.3 ± 0.1	7.5 ± 0.2	7.5 ± 0.7	7.6 ± 0.7	7.5 ± 0.07	7.6 ± 0.6	7.7 ± 0.07	7.8 ± 0.7	7.9 ± 0.7	7.1 ± 0.2	8 ± 0.1
Location (5)	7.5 ± 0.1	7.7 ± 0.7	7.4 ± 0.4	7.6 ± 0.7	7.7 ± 0.07	7.6 ± 0.70	7.7 ± 0.5	7.8 ± 1.0	7.9 ± 0.2	7.9 ± 0.5	7.2 ± 0.2	7.5 ± 0.5
Location (6)	7.7 ± 0.07	7.4 ± 0.2	7.9 ± 0.3	7.7 ± 0.1	7.7 ± 0.6	7.6 ± 0.8	7.6 ± 0.07	7.6 ± 0.2	7.7 ± 0.3	7.8 ± 0.9	7.8 ± 0.4	7.9 ± 0.2
Location (7)	7.5 ± 0.07	7.5 ± 0.4	7.5 ± 0.1	7.6 ± 0.7	7.7 ± 0.07	7.7 ± 0.07	7.7 ± 0.8	7.7 ± 0.2	7.8 ± 0.4	7.9 ± 0.7	7.4 ± 0.3	7.6 ± 0.07
Location (8)	7.3 ± 0.07	7.3 ± 0.7	7.3 ± 0.1	7.3 ± 0.07	7.4 ± 0.07	7.5 ± 0.3	7.6 ± 0.07	7.8 ± 0.7	7.9 ± 0.5	7.9 ± 0.8	7.4 ± 0.3	7.5 ± 0.4
Sampling sites	pH (Islamabad city)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Location (1)	7.2 ± 0	7.3 ± 0.07	7.05 ± 0.07	7.2 ± 0.2	7.15 ± 0.07	7.4 ± 0.28	7.5 ± 0.2	7.6 ± 0.28	7.7 ± 0.3	7.4 ± 0.15	7.6 ± 0.04	7.25 ± 0.07
Location (2)	7.3 ± 0.14	7.4 ± 0.07	7.05 ± 0.35	7.3 ± 0.7	7.35 ± 0.07	7.6 ± 0.07	7.6 ± 0.07	7.7 ± 0.07	7.8 ± 0.07	7.5 ± 0.14	7.5 ± 0.14	7.35 ± 0.21
Location (3)	7.4 ± 0.2	7.3 ± 0.28	7.15 ± 0.63	7.1 ± 0.1	7.7 ± 0	7.3 ± 0.14	7.4 ± 0.14	7.5 ± 0.14	7.6 ± 0.14	7.35 ± 0.12	7.7 ± 0	7.5 ± 0.3
Location (4)	7.5 ± 0.1	7.3 ± 0.14	7.15 ± 0.49	7.5 ± 0.7	7.7 ± 0.14	7.5 ± 0.07	7.6 ± 0.07	7.7 ± 0.07	7.9 ± 0.7	7.4 ± 0.32	7.65 ± 0.07	7.65 ± 0.21
Location (5)	7.25 ± 0.07	7.1 ± 0	7.1 ± 0.28	7.6 ± 0.7	7.55 ± 0.21	7.6 ± 0.70	7.7 ± 0.07	7.8 ± 0.07	7.9 ± 0	7.7 ± 0.21	7.5 ± 0.14	7.5 ± 0.5
Location (6)	7.35 ± 0.07	7.2 ± 0.14	7.2 ± 0.56	7.7 ± 0.1	7.45 ± 0.07	7.6 ± 0.07	7.6 ± 0.07	7.6 ± 0.7	7.6 ± 0.07	7.8 ± 0.28	7.5 ± 0.56	7.9 ± 0.28
Location (7)	7.35 ± 0.03	7.15 ± 0.07	7.2 ± 0.14	7.6 ± 0.7	7.3 ± 0.14	7.7 ± 0.07	7.7 ± 0.8	7.7 ± 0.07	7.7 ± 0.07	7.6 ± 0.35	7.6 ± 0.35	7.6 ± 0.04
Location (8)	7.65 ± 0.49	7.45 ± 0.21	7.6 ± 0.56	7.3 ± 0.07	7.5 ± 0.35	7.5 ± 0.07	7.6 ± 0.07	7.8 ± 0.07	7.8 ± 0.07	7.3 ± 0.35	7.47 ± 0.28	7.5 ± 0.14

Sampling sites	Electrical conductivity (μs/cm) (Rawalpindi city)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Location (1)	450 ± 113.1	905 ± 49.4	1,225 ± 219.2	1,310 ± 14.1	1,290 ± 14.1	1,190 ± 14.1	1,090 ± 13.1	990 ± 12.2	890 ± 11	790 ± 9	1,135 ± 63.6	1,075 ± 120.2
Location (2)	670 ± 395.9	800 ± 42.4	595 ± 431.3	1,175 ± 120.2	1,075 ± 120.2	975 ± 120	875 ± 112	775 ± 102	675 ± 98	775 ± 78	360 ± 14.1	370 ± 14.1
Location (3)	1,015 ± 91.9	885 ± 7.07	630 ± 325.2	1,055 ± 219.2	955 ± 219.2	855 ± 219	755 ± 209	665 ± 200	555 ± 192	455 ± 102	1,115 ± 205	1,210 ± 311.1
Location (4)	985 ± 21.2	885 ± 7.07	1,185 ± 247.4	900 ± 98.9	800 ± 98.9	700 ± 98.9	600 ± 88.2	500 ± 98.9	400 ± 78.2	300 ± 68.1	1,105 ± 445.4	1,305 ± 452.5
Location (5)	985 ± 21.2	900 ± 98.9	1,105 ± 190.9	850 ± 28.2	750 ± 28.2	650 ± 28.2	550 ± 25.2	450 ± 28	350 ± 22.2	250 ± 15.2	630 ± 70.7	495 ± 176.7
Location (6)	360 ± 14.1	415 ± 91.9	425 ± 21.2	340 ± 42.4	340 ± 42.4	240 ± 42.4	140 ± 42.8	240 ± 42.4	340 ± 52.2	240 ± 42.3	360 ± 14.1	360 ± 0.3
Location (7)	975 ± 7.07	900 ± 113.1	885 ± 106	780 ± 28.2	680 ± 28.2	580 ± 28.2	480 ± 28.9	380 ± 26.2	280 ± 22.6	250 ± 20.3	985 ± 247.4	997 ± 14.1
Location (8)	690 ± 14.1	680 ± 0.3	860 ± 98.9	695 ± 7.07	595 ± 7.07	495 ± 7.07	395 ± 6.2	295 ± 5.8	195 ± 7.0	180 ± 2.3	610 ± 70.7	635 ± 35.3
Sampling sites	Electrical conductivity (μs/cm) (Islamabad city)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Location (1)	790 ± 84.85	800 ± 28.28	870 ± 70.71	860 ± 84.85	760 ± 84.85	1,180 ± 14.1	990 ± 14.14	950 ± 14.14	840 ± 14.14	840 ± 148.1	765 ± 21.21	765 ± 190.9
Location (2)	695 ± 7.071	685 ± 7.071	785 ± 70.71	755 ± 49.49	655 ± 49.49	995 ± 120	855 ± 120.2	785 ± 120.2	635 ± 120.2	755 ± 49.49	700 ± 14.14	785 ± 233.3
Location (3)	670 ± 98.99	670 ± 98.99	515 ± 35.35	515 ± 35.35	415 ± 35.35	840 ± 219	745 ± 219.2	695 ± 219.2	525 ± 219.2	785 ± 70.71	575 ± 7.07	445 ± 134.3
Location (4)	580 ± 0	640 ± 56.56	675 ± 49.49	685 ± 35.35	585 ± 35.35	710 ± 98.9	630 ± 98.99	560 ± 98.99	470 ± 78.2	715 ± 21.21	625 ± 7.07	560 ± 42.42
Location (5)	690 ± 0	735 ± 63.63	720 ± 14.14	715 ± 21.21	615 ± 21.21	670 ± 28.2	540 ± 28.28	450 ± 28.28	390 ± 22.2	490 ± 212.1	680 ± 42.42	530 ± 14.14
Location (6)	700 ± 42.42	715 ± 21.21	595 ± 148.4	560 ± 98.99	460 ± 98.99	280 ± 42.4	160 ± 42.42	290 ± 42.42	380 ± 52.2	685 ± 63.63	670 ± 42.42	640 ± 28.28
Location (7)	630 ± 141.4	685 ± 63.63	685 ± 63.63	650 ± 113.1	680 ± 113.1	670 ± 28.2	460 ± 28.28	310 ± 28.28	270 ± 22.6	615 ± 21.21	580 ± 56.56	530 ± 0
Location (8)	500 ± 197.9	490 ± 212.1	395 ± 21.21	375 ± 7.071	175 ± 7.071	495 ± 7.07	365 ± 7.071	255 ± 0.071	290 ± 7.0	710 ± 98.91	360 ± 14.14	330 ± 0

Sampling sites	Total dissolved solid (TDS) (ppm) (Rawalpindi city)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Location (1)	315 ± 190	445 ± 21.2	605 ± 106	685 ± 7.07	665 ± 7.07	645 ± 7.7	625 ± 7.1	605 ± 7.0	635 ± 6.6	585 ± 7.7	565 ± 35.3	505 ± 21.1
Location (2)	635 ± 233	465 ± 77.7	340 ± 212	610 ± 14.1	540 ± 66.5	510 ± 42.4	490 ± 42.2	470 ± 42.6	450 ± 42.4	390 ± 32.1	175 ± 7.07	330 ± 226
Location (3)	585 ± 162	465 ± 49.4	310 ± 169	590 ± 14.1	565 ± 7.07	545 ± 7.7	525 ± 7.1	505 ± 7.0	485 ± 7.6	438 ± 12.0	405 ± 106	400 ± 155
Location (4)	490 ± 14.1	465 ± 49.4	590 ± 127	430 ± 28.2	410 ± 28.2	390 ± 28.2	370 ± 28.8	350 ± 28.4	330 ± 28.2	320 ± 22.2	290 ± 226	270 ± 226
Location (5)	470 ± 28.2	430 ± 28.2	550 ± 98.9	350 ± 42.4	330 ± 42.4	310 ± 42.4	290 ± 42.2	270 ± 42.6	255 ± 49.4	245 ± 25.3	225 ± 35.3	220 ± 84.8
Location (6)	175 ± 7.07	425 ± 21.2	205 ± 7.07	170 ± 0.1	155 ± 7.07	135 ± 7.0	115 ± 7.7	135 ± 7.1	155 ± 7.0	160 ± 14.3	175 ± 7.07	180 ± 14.1
Location (7)	480 ± 0.2	440 ± 56.5	435 ± 49.4	370 ± 28.2	350 ± 28.2	330 ± 28.2	310 ± 28.4	290 ± 28.2	270 ± 28.1	265 ± 18.3	285 ± 120	375 ± 7.07
Location (8)	675 ± 21.2	660 ± 0	425 ± 49.4	330 ± 14.1	310 ± 14.1	290 ± 14.1	270 ± 14.4	250 ± 14.2	230 ± 14.1	240 ± 24.2	295 ± 35.3	300 ± 28.2
Sampling sites	Total dissolved solid (TDS) (ppm) (Islamabad city)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Location (1)	390 ± 42.42	430 ± 42.42	430 ± 42.42	425 ± 49.49	405 ± 49.49	645 ± 7.071	635 ± 7.071	635 ± 7.071	635 ± 6.63	665 ± 7.071	565 ± 35.35	375 ± 7.071
Location (2)	340 ± 0	335 ± 7.071	385 ± 7.071	370 ± 28.28	350 ± 28.28	550 ± 42.42	480 ± 42.42	430 ± 42.42	450 ± 42.42	275 ± 35.35	175 ± 7.071	345 ± 7.071
Location (3)	325 ± 49.49	325 ± 49.49	250 ± 14.14	250 ± 14.14	230 ± 14.14	510 ± 7.071	515 ± 7.071	580 ± 7.071	485 ± 7.071	790 ± 28.28	805 ± 106.1	280 ± 0
Location (4)	340 ± 0	310 ± 28.28	330 ± 28.28	335 ± 21.21	315 ± 21.21	390 ± 28.28	360 ± 28.8	385 ± 28.28	330 ± 28.28	650 ± 28.28	690 ± 226.2	305 ± 7.071
Location (5)	340 ± 0	360 ± 28.28	355 ± 7.701	350 ± 14.14	330 ± 14.14	380 ± 42.42	280 ± 42.2	210 ± 42.42	255 ± 49.49	440 ± 33.35	305 ± 35.35	355 ± 21.21
Location (6)	310 ± 7.710	360 ± 14.14	285 ± 7.071	270 ± 56.56	250 ± 56.56	190 ± 7.071	105 ± 7.071	235 ± 7.071	155 ± 7.071	375 ± 28.28	175 ± 7.071	325 ± 21.21
Location (7)	310 ± 7.710	350 ± 35.35	335 ± 35.35	320 ± 56.56	300 ± 56.56	370 ± 28.28	300 ± 28.28	260 ± 28.28	270 ± 28.228	590 ± 120.1	485 ± 120.2	280 ± 28.28
Location (8)	245 ± 91.92	235 ± 106.0	190 ± 14.14	180 ± 0	165 ± 7.071	230 ± 14.14	250 ± 14.4	270 ± 14.14	230 ± 14.14	280 ± 35.35	295 ± 35.35	175 ± 7.071

Sampling sites	Dissolved oxygen (mg/L) (Rawalpindi city)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Location (1)	6.4 ± 0.3	4.9 ± 0.07	4.5 ± 0.4	4.05 ± 0.2	3.7 ± 0.07	2.75 ± 0.07	3.6 ± 0.1	3.8 ± 0.4	4 ± 0.4	4.5 ± 2.1	5.6 ± 0.28	4.5 ± 0.6
Location (2)	6.5 ± 0.7	5.05 ± 0.07	4.8 ± 0.3	4.3 ± 0.3	3.9 ± 0.1	2.85 ± 0.07	3.55 ± 0.3	3.75 ± 0.5	3.95 ± 0.3	4.8 ± 5.5	6.1 ± 0.5	4.5 ± 0.7
Location (3)	6.3 ± 0.4	4.8 ± 0.07	4.7 ± 0.07	4.3 ± 0.4	3.6 ± 0.07	2.65 ± 0.7	3.65 ± 0.1	3.85 ± 0.7	4.05 ± 0.6	4.7 ± 8.6	5.6 ± 0.1	4.3 ± 0.6
Location (4)	6.5 ± 0.1	4.8 ± 0.07	4.7 ± 0.7	4.1 ± 0.07	3.1 ± 0.07	2.15 ± 0.1	3.15 ± 0.6	3.35 ± 0.7	3.55 ± 0.1	4.5 ± 22.3	5.8 ± 0.7	4.7 ± 0.4
Location (5)	6.5 ± 0.1	4.8 ± 0.2	4.7 ± 0.3	4.2 ± 0.5	3.2 ± 0.3	2.25 ± 0.3	3.25 ± 0.5	3.45 ± 0.3	3.65 ± 0.3	4.6 ± 12.5	5.9 ± 0.4	4.7 ± 0.7
Location (6)	6.6 ± 0.2	4.7 ± 0.8	4.8 ± 0.1	4.4 ± 0.4	3.4 ± 0.2	2.4 ± 0.4	3.4 ± 0.2	3.6 ± 0.4	3.8 ± 0.6	4.8 ± 6.9	6.1 ± 0.5	4.6 ± 0.7
Location (7)	6.6 ± 0.4	5 ± 0.14	4.6 ± 0.2	4.3 ± 0.1	3.3 ± 0.2	2.35 ± 0.1	3.35 ± 0.2	3.55 ± 0.3	3.75 ± 0.4	4.5 ± 24.6	6.0 ± 0.6	4.9 ± 0.4
Location (8)	6.3 ± 0.1	4.9 ± 0.4	4.7 ± 0.5	4.1 ± 0.2	3.1 ± 0.2	2.15 ± 0.2	3.15 ± 0.3	3.35 ± 0.3	3.55 ± 0.4	5.0 ± 36.2	5.9 ± 0.6	4.9 ± 1.0
Sampling sites	Dissolved oxygen (mg/L) (Islamabad city)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Location (1)	5.8 ± 0.353	5.4 ± 0.070	4.5 ± 0.282	4.2 ± 0.141	3.8 ± 0.141	2.8 ± 0.070	3.6 ± 0.141	3.9 ± 0.070	4.3 ± 0.141	5.8 ± 0.282	5.6 ± 0.28	5.5 ± 0.141
Location (2)	5.7 ± 0.141	5.4 ± 0.070	4.2 ± 0	4.0 ± 0.353	3.5 ± 0.353	2.9 ± 0.070	3.6 ± 0.353	3.9 ± 0.353	4.1 ± 0.353	6.5 ± 0.282	6.1 ± 0.535	5.3 ± 0
Location (3)	6.1 ± 0.424	5.3 ± 0.070	4.4 ± 0.353	4.3 ± 0.353	3.4 ± 0.353	2.7 ± 0.070	3.7 ± 0.070	3.8 ± 0.070	4.1 ± 0.565	5.3 ± 0.070	5.6 ± 0.141	5.6 ± 0.070
Location (4)	6.5 ± 0	5.1 ± 0.070	4.3 ± 0.141	4.1 ± 0.353	3.3 ± 0.353	2.2 ± 0.070	3.2 ± 0.353	3.5 ± 0.141	3.6 ± 0.070	5.3 ± 0.282	5.8 ± 0.070	5.5 ± 0.070
Location (5)	6.0 ± 0	4.8 ± 0.282	4.3 ± 0.171	4.2 ± 0.141	3.2 ± 0.141	2.3 ± 0.353	3.3 ± 0.353	3.5 ± 0.565	3.7 ± 0.212	5.4 ± 0.353	5.9 ± 0.414	5.4 ± 0.070
Location (6)	5.8 ± 0.282	5.1 ± 0.141	4.2 ± 0.141	4.4 ± 0.141	3.3 ± 0.141	2.4 ± 0.424	3.4 ± 0.424	3.6 ± 0.414	3.4 ± 0.353	5.1 ± 0.070	6.1 ± 0.535	5.2 ± 0.070
Location (7)	6.1 ± 0.141	5.3 ± 0.141	4.3 ± 0.565	4.3 ± 0	3.3 ± 0.070	2.4 ± 0.212	3.4 ± 0.212	3.6 ± 0.353	3.8 ± 0.414	6.1 ± 0.424	6.0 ± 0.242	5.3 ± 0.282
Location (8)	6.7 ± 0.212	5.6 ± 0.070	4.7 ± 0.141	4.1 ± 0.494	3.2 ± 0.212	2.2 ± 0.212	3.2 ± 0.212	3.4 ± 0.212	3.6 ± 0.414	5.5 ± 0.212	5.9 ± 0.242	5.5 ± 0.494

Sampling sites	Temperature (°C) (Rawalpindi city)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Location (1)	23.7 ± 2.4	20.6 ± 0.6	24.2 ± 5.7	27.6 ± 0.9	27.6 ± 0.9	27.6 ± 0.9	27.8 ± 0.8	28 ± 0.9	28.2 ± 0.4	26.8 ± 0.8	24.5 ± 0.1	21 ± 0.1
Location (2)	23.5 ± 2.2	20.7 ± 0.2	24.1 ± 5.5	27.3 ± 1.0	27.3 ± 1.0	27.3 ± 1.0	27.8 ± 1.6	28.1 ± 1.7	28.4 ± 1.2	25.3 ± 12	20.5 ± 0.1	20.5 ± 0.2
Location (3)	23.4 ± 2.1	20.8 ± 0.6	24 ± 5.2	27.2 ± 0.7	27.2 ± 0.7	27.2 ± 0.7	27.5 ± 0.9	28.3 ± 0.6	28.6 ± 0.8	23.2 ± 14	20.5 ± 0.2	20.4 ± 0.07
Location (4)	23.1 ± 2.1	20.8 ± 0.6	24.3 ± 5.8	27.5 ± 1.4	27.5 ± 1.4	27.5 ± 1.4	27.9 ± 1.3	28.3 ± 1.5	28.9 ± 1.3	22.2 ± 19	20.4 ± 0.2	20.4 ± 0.1
Location (5)	23.0 ± 2.1	21.4 ± 0.1	24 ± 5.6	27.3 ± 0.9	27.3 ± 0.9	27.3 ± 0.9	27.8 ± 0.1	28.2 ± 0.8	28.5 ± 0.9	23.6 ± 16	20.5 ± 0.3	20.6 ± 0.4
Location (6)	22.6 ± 2.8	21 ± 0.5	24.5 ± 4.5	27.2 ± 0.7	27.2 ± 0.7	27.2 ± 0.7	27.8 ± 0.5	27.9 ± 0.8	28.3 ± 0.4	21.3 ± 11	20.3 ± 0.2	20.7 ± 0.9
Location (7)	23.1 ± 1.9	20.4 ± 0.4	24.2 ± 5.0	27.2 ± 0.8	27.2 ± 0.8	27.2 ± 0.8	27.6 ± 0.4	28 ± 0.8	28.2 ± 0.5	24.1 ± 10	20.4 ± 0.3	20.5 ± 0.1
Location (8)	24.0 ± 0.07	20.0 ± 0.7	23.8 ± 4.6	26.9 ± 0.2	26.9 ± 0.2	26.9 ± 0.2	27.3 ± 0.8	27.6 ± 0.4	28.1 ± 0.7	21.9 ± 9	20.8 ± 0.4	20.1 ± 0.07

Sampling sites	Temperature (°C)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Location (1)	24.4 ± 4.808	19.7 ± 0.494	24.3 ± 4.38	26.7 ± 0.98	26.7 ± 0.98	27.6 ± 0.98	26.6 ± 0.98	27.6 ± 0.98	28.3 ± 0.4	21.5 ± 0.1	20.5 ± 0.70	18.6 ± 2.19
Location (2)	24.1 ± 4.38	20.3 ± 0.989	24.4 ± 4.03	26.6 ± 0.84	26.6 ± 0.84	27.4 ± 1.06	27.4 ± 1.06	27.4 ± 1.06	28.6 ± 1.2	21.8 ± 0.1	20.5 ± 0.49	18.3 ± 2.54
Location (3)	24.0 ± 4.24	20.3 ± 1.060	26.6 ± 1.06	26.6 ± 1.06	26.6 ± 1.06	27.2 ± 0.70	27.2 ± 0.70	27.3 ± 0.70	28.3 ± 0.8	21.3 ± 0.2	20.4 ± 0.49	18.5 ± 2.26
Location (4)	26.8 ± 0	20.0 ± 0.494	24.5 ± 3.39	26.4 ± 0.77	26.4 ± 0.77	27.5 ± 1.41	27.5 ± 1.41	27.5 ± 1.41	28.6 ± 1.3	20.9 ± 0.2	20.4 ± 0.21	18.4 ± 2.68
Location (5)	23.7 ± 4.59	20.0 ± 0.565	24.2 ± 3.39	26.3 ± 0.49	26.3 ± 0.49	27.3 ± 0.98	27.4 ± 0.91	27.4 ± 0.91	28.9 ± 0.9	20.7 ± 0.3	20.4 ± 0.35	18.6 ± 2.75
Location (6)	23.9 ± 4.10	20.4 ± 0.565	28.5 ± 77.7	26.3 ± 0.77	26.3 ± 0.77	27.2 ± 0.77	27.3 ± 0.77	27.3 ± 0.77	28.5 ± 0.4	20.7 ± 0.2	20.3 ± 0.35	18.8 ± 2.89
Location (7)	23.9 ± 4.10	20.4 ± 0.919	23.5 ± 4.94	26.4 ± 0.91	26.4 ± 0.91	27.2 ± 0.84	27.2 ± 0.84	27.2 ± 0.8	28.6 ± 0.84	20.2 ± 0.3	20.4 ± 0.42	19.2 ± 2.12
Location (8)	23.6 ± 3.88	20.3 ± 1.060	23.2 ± 4.87	26.2 ± 0.63	26.2 ± 0.63	26.9 ± 0.28	26.9 ± 0.28	27.6 ± 0.4	26.9 ± 0.28	20.1 ± 0.4	20.5 ± 0.07	19.2 ± 2.47