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Assessment of drinking water quality and its potential health impacts in academic institutions of Abbottabad (Pakistan)

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ABSTRACT

The continuously deteriorating water quality situation in Pakistan is posing serious health threats to the population. The study aimed to assess the physicochemical and bacteriological quality of drinking water in different institutions of Abbottabad city and its potential health effects on staff and students. About 63 samples from 60 institutions across different locations of Abbottabad city were analysed for physicochemical (temperature, pH, total dissolved solids (TDS) and electrical conductivity (EC)) and bacteriological (total coliforms and *Escherichia coli*) analysis using standard methods. Water quality ($n = 60$) and health related ($n = 300$) information was obtained through pre-designed survey questionnaires. Results showed that all water samples were aesthetically acceptable. In physicochemical analysis, the mean temperature and pH values were found at 27.12 ± 2.47°C and 7.98 ± 0.24, respectively. The mean TDS and EC values were found at 335.42 ± 86.3 ppm and 647.38 ± 174.82 μS, respectively. Bacteriological analysis showed that THBC in water samples ranged from 10 to 58000 CFU/ml with 63.5% samples exceeding the WHO drinking water quality limits. Results of total coliform analysis showed most-probable-number values ranged between 0 and > 2400 per 100 ml with 42 samples (66.6%) exceeding permissible limits. After isolation, identification of strains was performed by API 20E Identification System. Three pathogenic species namely *Citrobacter sakazakii*, *Enterobacter cloacae* and *Salmonella choleraesius* were identified. Data obtained through questionnaires identified three major sources of drinking water i.e. government supply, bore well and tube well. Most of the secondary level institutions used government supply (54%), higher secondary institutions used bore well (53%) and post secondary institutions used tube wells (44%) to meet their drinking water needs. Bore well was found to be the most widely used source. Majority of institutions i.e. 75% secondary, 47% higher secondary and 39% post secondary consumed water without any prior treatment. Respondents reported diseases in the order of typhoid > diarrhoea > dysentery > hepatitis > abdominal pains > skin infections. Disease prevalence in secondary institutions was found higher as compared to the higher and secondary institutions. Presence of total coliforms in 66.6% of water samples clearly indicates the need of monitoring at regular intervals, effective treatment processes and sound policy recommendations in Abbottabad city.

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Keywords: Water quality; Waterborne diseases; Health impacts; Abbottabad city; Total coliform

1. Introduction

The quality of drinking water is directly associated with human health and indicates the effectiveness of environmental protection measures [1]. About 2.6% of the total water pool on earth exists as freshwater. However, the amount of freshwater available for human use is estimated at only 0.01%. Over the last century, rapid population growth and unchecked developmental activities have increased the global demand for freshwater resource on one hand and lead to deterioration of its quality on the other [2]. According to Kovacs [3], integration of various environmental factors contributes to the pollution of surface water bodies. Apart from unregulated industrial effluents and accidental spills, other issues such as urbanization, deforestation, erosion, intensified agriculture and non-point sources are also aggravating this problem. The unchecked use of new technologies for strongly entrenched agricultural and manufacturing interests is leading to substantial decrease in availability and quantity of clean water [4]. Weather events and anthropogenic activities influence physicochemical characteristics of water, which further affect its biological quality [5]. The contamination of drinking water with hospital, industrial and sewage wastewater through leakages in piped networks is also a major health concern [6].

Water quality deterioration is a global problem. However, the situation is worse in the developing world due to lack of professional expertise, management systems and financial resources [7]. In order to reduce global disease burden, the need for providing access to adequate quantity of safe drinking water has been clearly recognized in the Millennium Development Goals. However, around 900 million people are still deprived of adequate safe drinking water supplies [8]. Various water-related diseases associated with poor drinking water quality account for around 5 million deaths annually, which are 10 times greater than causalities of wars on an average [9]. The mechanism for quality monitoring and assurance of drinking water is also absent or poorly devised in developing countries posing serious health threats to the population [10].

Pakistan is water-stressed country and stands 80th among the list of 122 countries for quality of potable water [9]. About 61% of the total population (85% urban and 47% rural) has access to safe drinking water through pipeline networks [11]. About 93% of the available water is utilized for irrigation purposes and 40 million people rely on this irrigation water for meeting their domestic needs. However, due to severe bacteriological contamination, this source often does not comply with even irrigation water standards. Waterborne diseases account for 250,000 infant deaths each year. Municipalities are also supplying contaminated drinking-water to the communities. The discharge of wastewater from domestic, municipal and industrial sectors directly into water bodies without proper treatment is major cause of surface and groundwater pollution in Pakistan [12]. Damaged pipeline networks with intermittent water supply often pass through street drains and even safe drinking water in the distribution network becomes vulnerable by contamination through leakages [13]. Water quality analyses from previous studies [14–18] have shown that drinking water in Abbottabad and the surrounding areas of KPK province is highly contaminated and requires adequate treatment before use. The data for monitoring, treatment facility and quality of water at the point of use in academic institutions were not available. The research aimed to assess the quality of drinking water quality and associated health risks in academic institutions of Abbottabad city.

2. Materials and methods

2.1. Description of the study area

The study was conducted in densely populated area of Abbottabad city, district Abbottabad, Khyber Pakhtunkhwa Province, Pakistan. Abbottabad district is situated in predominantly mountainous terrain, between 33° 50′ and 34° 23′ North latitudes and 73° 35′ and 73° 31′ East longitudes, with average elevation of peaks ranging between 2,500 and 2,700 m above sea level. The mean elevation of the Abbottabad city is 1,256 m (4,120 feet) above sea level. The city is situated at the base of Himalayan range in the active monsoon zone. It is surrounded by Sarban hills and experiences a cool temperate climate throughout most of the year. The mean maximum and minimum annual temperatures of the Abbottabad district range between 22.76 and 11.41°C, respectively, while the average annual precipitation has been recorded at 1,366.18 mm. The temperature falls below 0°C during winters, with heavy snowfall in the surrounding forest covered hills. The average relative humidity in the district has been recorded at 56%. With population density of 447 persons/km^2, it is the fifth largest district in the Khyber Pakhtunkhwa Province, after Bannu, Charsadda, Mardan and Peshawar [19,20]. A map of the study area along with the sampling points was generated in ArcGIS 10.0 Desktop Software (Fig. 1).

2.2. Sample collection and preservation

A total of 63 samples were collected from 60 representative academic institutions in different areas of

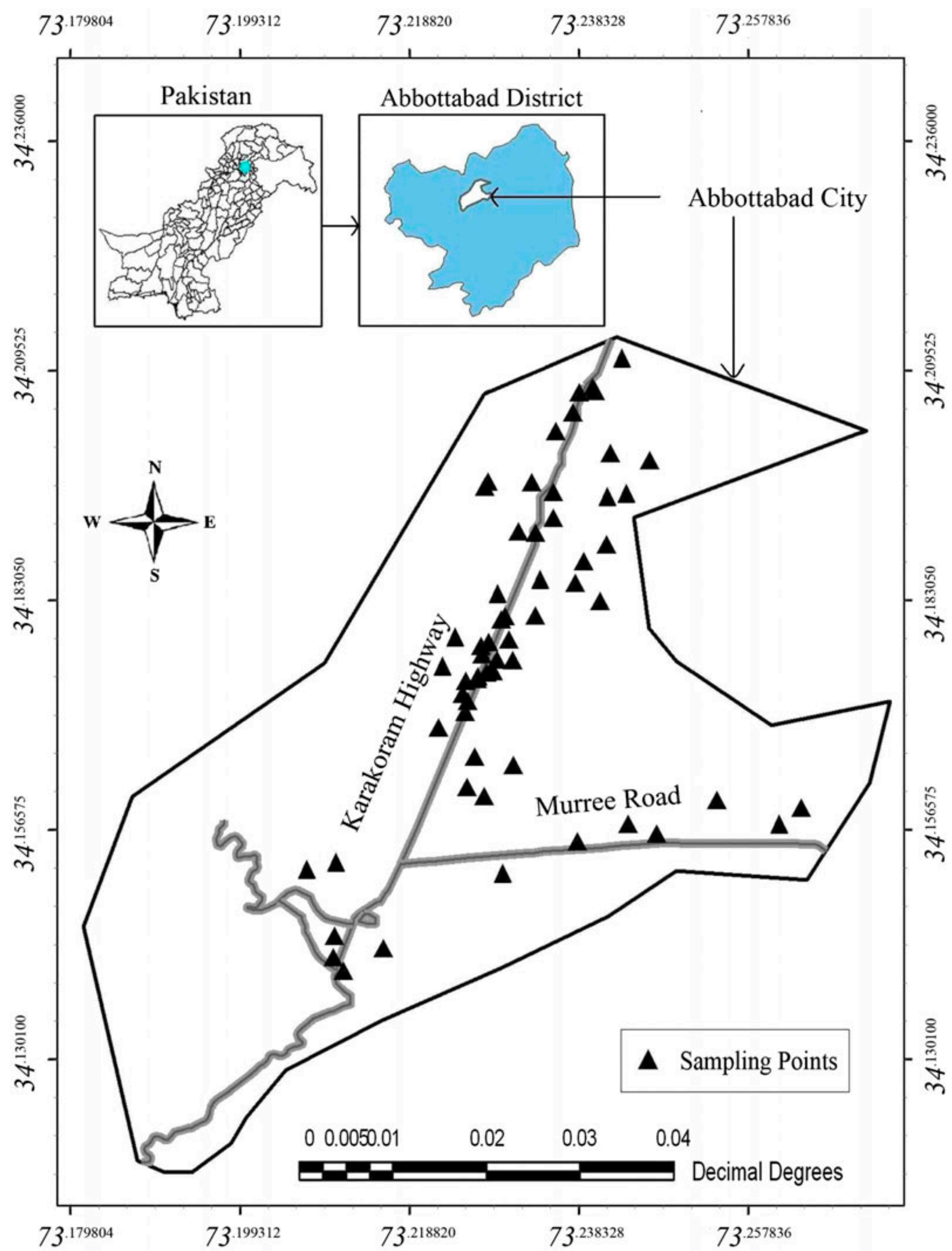

Fig. 1. GIS map of the study area.

Abbottabad city. The institutions were selected randomly and categorized into: up to secondary, up to higher secondary and post secondary levels. Since some secondary level institutions also included primary education, comparatively greater number of institutions in up to secondary category was selected. All the sampling procedures were carried out according to the guidelines prescribed by Standard Methods for Examination of Water and Wastewater [21] and Manual of Clinical Microbiology [22]. Two to three drops of 3% sodium thiosulphate solution were added to the bottles before sterilization for neutralizing the bactericidal effects of any chlorine content present in the samples. Grab samples were collected at the point of use manually. At institutions where more than one source was identified, number of samples was increased. The sample bottles were preserved in a basket fitted with ice to limit bacterial growth at 4–8˚C, and was carried to the laboratory for analysis within 4–5 h of collection.

2.3. Analytical procedures

All the chemicals and equipments used in the analysis were of lab grade purchased from E. Merck. Analyses of the physicochemical parameters, such as taste, colour, odour, temperature, pH, total dissolved solids (TDS) and EC were performed on site according to standard methods [21,23]. Parameters, such as TDS, EC and temperature were recorded through a calibrated combo metre (HANNA, HI 98129). The pH of the water samples was measured with a calibrated pH metre (Eutech, Eco Testr pH 1). The bacteriological quality analysis of water samples was conducted by total heterotrophic bacterial count (THBC) and most probable number (MPN) techniques. THBC was determined through spread plate technique according to standard methods [21]. The sample was serially diluted in order to obtain a desirable colony count (30–300 CFUs). Nutrient agar media was used to observe the growth of heterotrophic bacteria at 27˚C for 18–24 h. The contamination of water samples with total coliform bacteria was analyzed through MPN technique according to standard method [21]. MacConkey broth was used for presumptive test. Positive tubes were further inoculated in brilliant green lactose broth to confirm the presence of coliforms. All confirm positive tubes were inoculated in peptone water and the indole test was performed for confirmation of *Escherichia coli*.

Identification of strains was performed through standard methods [22]. Pure culture was obtained using streak plate method and morphology of strains was determined by Gram staining technique. Analytical profile index for Enterobacteriaceae (API 20E, bioMérieux's) was purchased from global marketing services and used to identify different bacterial strains.

2.4. Health impact study

A water quality survey questionnaire was developed to obtain information related to water quality, such as source of water, treatment facility, material of storage tanks and sanitary conditions from staff responsible for maintenance of water facilities at academic institutions ($n = 60$). A separate health questionnaire was also developed to collect data from five persons including principal and teachers ($n = 300$) in different institutions. The health questionnaire aimed at assessing the prevalence of different water-related diseases among students and staff in academic institutions.

3. Results and discussion

3.1. Physicochemical and aesthetic quality analysis

Aesthetic aspects, such as taste, odour and colour of all 63 samples were tested and none of the samples were found objectionable for these parameters. All samples were found colourless, tasteless and odourless. Although various physicochemical factors, such as temperature, pH, TDS and EC may not have immediate and direct health effects, they widely influence and provide with the conditions suitable for survival of biological contaminants [17]. The physicochemical analyses included measurements of temperature, pH, TDS and EC of all 63 water samples on site. The results for physicochemical analysis are presented below.

3.1.1. Temperature and pH

The temperature of the samples was measured over late April to mid-June and ranged from minimum 21 to maximum 31.2˚C. The average temperature of the water samples was 27.12˚C. The significant variations in temperature of different samples can be attributed to diurnal and seasonal fluctuations, exposure of storage tank to direct sunlight and material of the tank. To avoid sampling of water from hot pipes, taps were left running for 2–3 min so that representative sample of the storage container is obtained. Sampling was started in rainy days at the end of April when temperatures were considerably mild with little to no sunlight intensity and lasted till relatively clear and hotter days of mid-June. WHO has rendered drinking water temperature >25˚C undesirable due to changes in acceptability and growth in population sizes of a number of species including *Aeromonas* spp., *Campylobacter* spp., *Legionella* spp. and *Vibrio cholerae* [23].

The pH of the water samples was found within the WHO limits of 6.5–8.5 except one sample with pH of 8.7 indicating the need for control measures. Although pH effects palatability and has usually no direct health impacts, it is an important operational water quality parameter. It determines the corrosive power of water. The disinfecting tendency of chlorine decreases above pH 8 and its corrosiveness increases below pH 7 [23]. About 62% of the water samples possessed pH of 8 or above. Higher levels of chlorine would thus be required to effectively disinfect these sources. However, pH of none of the samples was below 7. Mean temperature and pH values of water samples collected from three academic institution categories are illustrated in Fig. 2.

3.1.2. TDS and EC

The results showed that TDS values ranged from 135 to 720 ppm. Only one sample with TDS of 720 ppm exceeded the desirable limit and one was close to the limit with TDS of 557 ppm. In order to ensure palatability of drinking water, WHO has recommended TDS levels less than 600 ppm [23]. However, too low TDS levels can also impart insipid taste to water. Although TDS itself is only a secondary water quality parameter posing no direct health effects, it may indicate excessive presence of harmful ions including aluminium, arsenic, copper, lead and nitrate. Higher TDS levels can also cause scaling in pipes and other infrastructures [24].

The values of EC ranged between 258 and 1,383 μS/cm. WHO has not recommended any guideline value for EC. However, according to United States Public Health Service, EC in drinking water should not exceed 300 μS/cm [25]. EC of all water samples exceeded this limit except one sample with EC of 258 μS/cm. However, mean values for all institution categories exceeded the limit. The EC of water has direct relationship with TDS. With increase in concentration of dissolved salts in water (salts of sodium, calcium and magnesium, bicarbonate, chloride and sulphate), EC also increases [25]. Mean values for TDS and EC of water samples are given in Fig. 3.

3.2. Bacteriological analysis of water samples

Bacteriological analysis (THBC, total coliforms and *E. coli*) of all 63 water samples was performed and the results of these parameters are given below.

3.2.1. Total heterotrophic bacterial count

The examination of total heterotrophic bacteria indicated that quality of water at higher and post secondary level institutions was better as compared to secondary level institutions (Fig. 4). The THBC of samples ranged from minimum of 10 to maximum of 58,000 CFU/ml. These results are in line with previous studies which state that one of the major problems regarding water quality in rural as well as urban areas of Pakistan is the heavy bacteriological contamination of drinking water sources [26]. The city was also affected with flooding events in 2010 and 2011. The key water and sanitation infrastructure often becomes entirely or partially damaged due to submergence in flooding events. The physicochemical and microbial degradation of water quality in disaster situations aggravate the prevalence of various waterborne diseases [27]. THBC indicates effectiveness of bacterial disinfection and hygienic conditions of storage tanks and distribution system. Due to likely presence of potentially opportunistic pathogens in THBC, WHO drinking water quality guidelines have suggested THBC values of not more than 300 CFU/ml in drinking water in distribution lines and 20 CFU/ml for treated water [23]. A total of 63.5% samples exceeded standard guideline values.

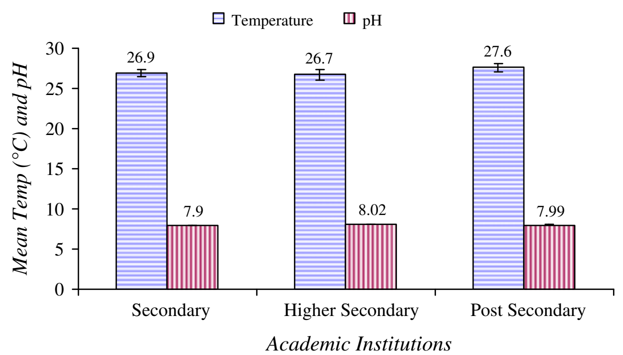

Fig. 2. Mean temperature and pH of water samples.

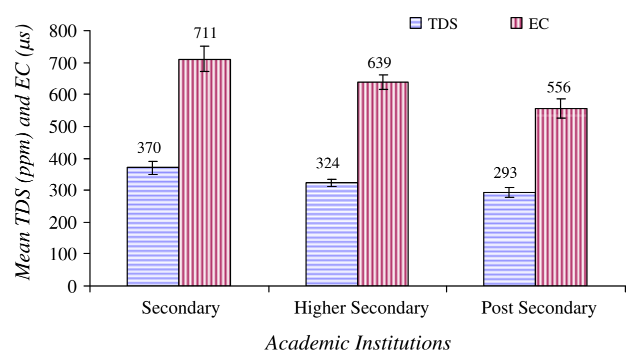

Fig. 3. Mean TDS and EC of water samples.

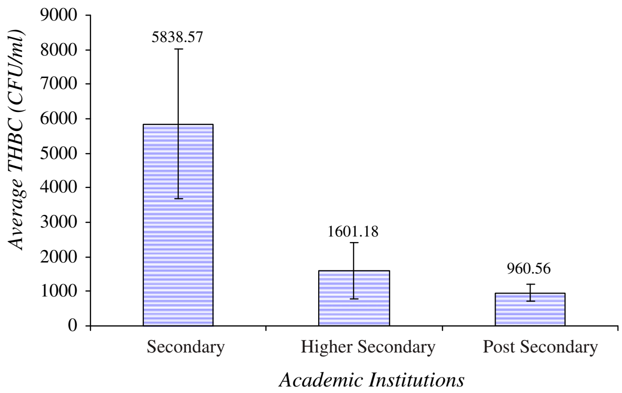

Fig. 4. Mean THBC of water samples.

3.2.2. Total coliform and faecal coliform count

The values for total coliforms ranged from minimum 0 to maximum of >2,400 MPN/100 ml. WHO recommends total coliform limit of 0 MPN/100 ml [23], which was exceeded in 66.6% of the samples. Mean total coliform values of three institution categories are presented in Fig. 5, which indicates overall poor water quality situation of the majority institutions in study area. Comparatively higher total coliform concentrations in secondary institutions represent the need for immediate and effective control measures. Total coliform bacteria include a wide range of aerobic and facultatively anaerobic, Gram-negative, non-spore-forming bacilli capable of growing in the presence of relatively high concentrations of bile salts with the fermentation of lactose and production of acid or aldehyde within 24 h at 35–37˚C. Total coliforms serve as indicators of cleanliness and integrity of storage facilities and distribution network [23]. All water samples were examined with indole test for presence of *E. coli*. However, *E. coli* was not confirmed in any of the samples. The further tests by API 20E Identification System also confirmed the absence of *E. coli*.

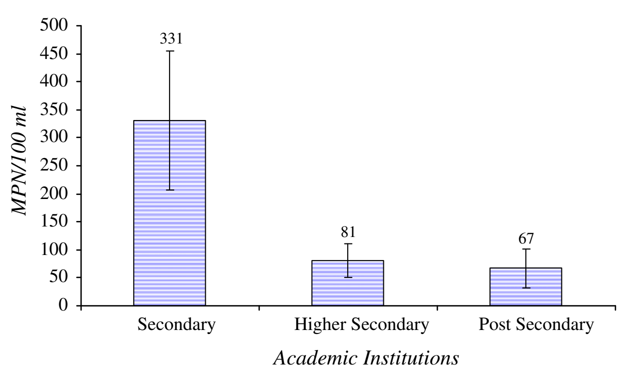

Fig. 5. Mean MPN values of water samples.

3.3. Overview of bacteriological quality in academic institutions

About 82, 64.7 and 44% of the water samples in secondary, higher secondary and post secondary institutions exhibited bacteriological contamination beyond permissible limits. Overall, about 66.6% of the total water samples were not meeting the standard criteria of WHO. An overview of bacteriological contamination detected in academic institutions of Abbottabad city is presented in Table 1.

3.4. Identification of bacterial strains

The isolation of pure culture and subsequent identification through Gram-staining and API 20E Identification System detected three different pathogenic species i.e. *Citrobacter sakazakii*, *Enterobacter cloacae* and *Salmonella choleraesius*. Different biochemical characteristics exhibited by these species are shown in Tables 2 and 3. These species are opportunistic pathogens and pose life-threatening health risks [28–30].

3.5. Health impact study

3.5.1. Sources of drinking water

The three major sources of drinking water identified at different institutions were government supply, bore wells and tube wells. The three institution categories use different supply options as illustrated in Fig. 6. Groundwater is less exposed to pollutants and thus has better quality compared to surface water sources [31]. The general opinion of respondents also endorsed this point of view. Most institutions, 43% secondary, 53% higher secondary and 28% post secondary had bore well supply. Institutions with more financial stability, 44% post secondary, 23% higher secondary and 3% secondary, preferred tube well water to meet their drinking water needs. The institutions using government supply wanted to have private borings, but were financially restrained. Institutions using bore well or tube well also used government supply water but for purposes other than drinking such as hygiene maintenance. The source of water used in academic institutions of Abbottabad city was thus found to be closely related with financial strength of the institution.

Table 1
Overview of bacteriological water quality in academic institutions

Category	No. of samples	Total coliform	*E. coli*	Exceeding THBC limit	Samples exceeding standards (%)
Secondary	28	23	0	19	82.1
Higher secondary	17	11	0	10	64.7
Post secondary	18	8	0	11	44.4
Total	63	42	0	40	66.6

Table 2
Biochemical characteristics of identified strains

S. no.	Characteristics	*C. sakazakii*	*E. cloacae*	*S. choleraesius* spp. *arizonae*
1	Morphology	Rods, single	Rods, single	Rods, single
2	Gram staining	−	−	−
3	Ortho-nitrophenyl-β-galactosidase (ONPG)	+	+	+
4	Arginine dihydrolase (ADH)	+	+	+
5	Lysine decarboxylase (LDC)	−	+	−
6	Ornithine decarboxylase (ODC)	+	+	+
7	Citrate test	+	+	+
8	H_2S production	−	−	+
9	Urease test	−	−	−
10	Tryptophan deaminase (TDA)	−	−	−
11	Indole test	−	−	−
12	Voges proskauer	+	−	−
13	Gelatin hydrolysis	+	−	−

Table 3
Fermentation of sugars by identified bacterial strains

		Sugars fermented by bacteria								
S. no.	Micro-organisms	GLU	MAN	INO	SOR	RHA	SUC	MEL	AMY	ARA
1	*C. sakazakii*	+	+	−	−	−	+	−	+	+
2	*E. cloacae*	+	+	−	+	+	+	+	+	+
3	*S. cholerasius*	+	+	−	+	+	+	+	−	+

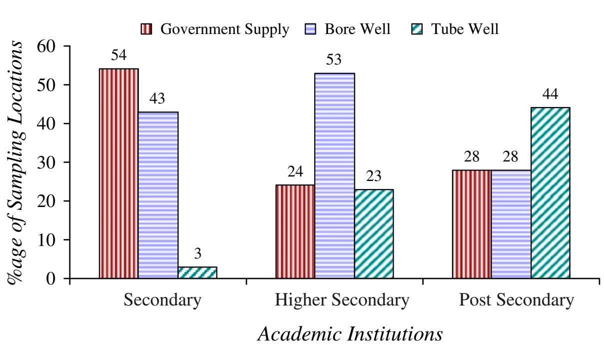

Fig. 6. Sources of drinking water in academic institutions.

3.5.2. Treatment facilities at academic institutions

Regardless of the source, institutions used UV filters as a preferred method to treat water. The consumption of water without any treatment by 75% secondary, 47% higher secondary and 39% post secondary institutions was probably either due to costs associated with filtration or the assumption that groundwater was always safe and needs no treatment before use. Even the need of boiling was not deemed necessary except one secondary level institution. Treatment facilities available at academic institutions are shown in Fig. 7. A previous study [14] in Abbottabad district found that people were unable to relate

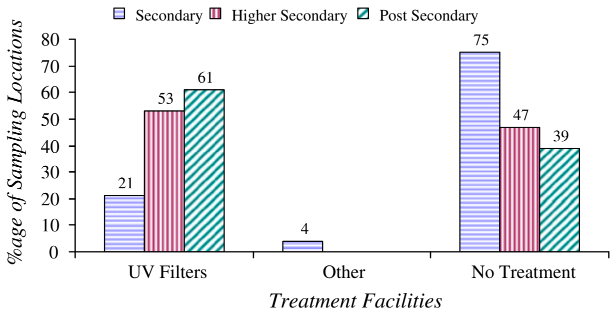

Fig. 7. Available treatment facilities at academic institutions.

poor sanitary conditions with adverse health impacts. The findings of this study also indicate that either people perceived water as safe or were unaware of the strong linkages between water quality and health. The limited effectiveness of the treatment facilities is probably due to lack of expertise in maintenance of filters [32]. The respondents used only subjective quality criteria, such as smell, taste, colour, turbidity and appearance to judge whether water was suitable for drinking. The quality of water also influences behaviour towards water consumption. Communities have taken action in response to contaminated drinking water and have been willing to pay for safe drinking water intervention [33].

3.5.3. Disease prevalence ratio in academic institutions

The data obtained through questionnaires revealed a number of diseases prevalent in the study area. Respondents from up to secondary level institutions reported most disease occurrences (13, 26, 17, 12, 15 and 12% prevalence of dysentery, typhoid, diarrhoea, hepatitis, abdominal pain and skin infections, respectively), while typhoid was the most widely reported disease (26, 18 and 21% in secondary, higher secondary and post secondary institutions, respectively). About 26% of the respondents reported no disease prevalence in the institutions. The isolation and identification of various pathogenic bacteria describes the link between poor water quality and these health impacts. Since the study could only encompass eight identification tests, further analysis would lead to more detailed depiction of the situation. The degraded microbiological water quality often leads to high incidence of waterborne illnesses [24]. Since students and staff spend considerable time at institutions and use drinking water sources, there was likelihood that these sources might be responsible for water-related diseases prevalent among them. The disease ratio in different academic institutions is illustrated in Fig. 8.

Even well protected and properly managed supply systems do not ensure safe delivery of drinking water at the consumer's end [23]. The deteriorating water quality situation in Pakistan, especially in rapidly growing urban settlements, requires regular monitoring both at the point of use and source [24]. The scope of the present study included physicochemical and bacteriological analysis of drinking water at academic institutions within the Abbottabad city. Although access to safe drinking water is the prime goal of public health authorities, findings of this study showed that existing system of drinking water supply was not dependable in terms of quality.

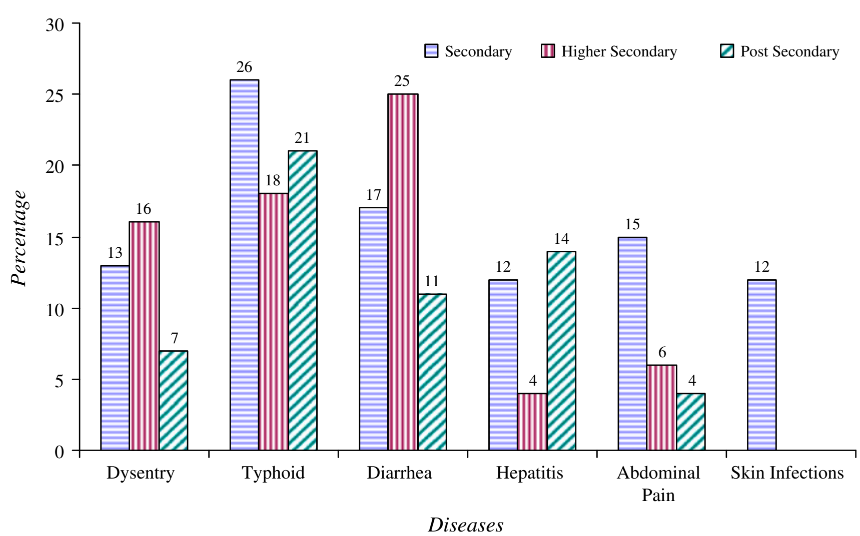

Fig. 8. Prevalence of different diseases in academic institutions.

4. Conclusions

Access to safe drinking water is a fundamental right, vital to ensure human health and well being. The study employed a set of standard methods along with survey questionnaires to assess the physicochemical and bacteriological quality of drinking water and its possible health impacts at different academic institutions in Abbottabad city.

Water quality situation both in terms of physicochemical and bacteriological aspects in all three institution categories was poor; particularly institutions up to secondary level were found more vulnerable to health risks. Presence of coliforms in 66.6% of water samples clearly point outs the limited the effectiveness of conventional treatment processes such as UV filters, boiling and chlorination in the study area. Institutions in Abbottabad city are increasingly relying on groundwater sources due to degraded surface water quality. The prevalence of diseases and total coliforms count in drinking water of the study area indicate a positive correlation between water quality and health. No growth of *E. coli* was found in all the tested samples. The identification of pathogenic *Enterobacter*, *Citrobacter* and *Salmonella* species is indicative of poor waste and wastewater management practices in the study area, and point outs the need for monitoring of water sources at regular intervals, effective treatment processes and sound policy recommendations in Abbottabad city.

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