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Physico-chemical and bacteriological analysis of tap water of a Residential University of Pakistan

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Abstract

Regular monitoring and management of drinking water is necessary to ensure public health. This study was performed to examine the physico-chemical and bacteriological quality of tap water of a residential university (National University of Sciences and Technology, NUST) in Pakistan. Samples were obtained from six randomly selected institutes of NUST for a period of four months (November-2019, December-2019, January-2020 and February-2020) to evaluate variations in selected parameters. Ten physicochemical parameters were analyzed pH, Electrical conductivity (EC), Dissolved oxygen (DO), Alkalinity, Hardness, Total organic carbon (TOC), Total dissolved solids (TDS), Total suspended solids (TSS), Turbidity, Free and total chlorine. Bacteriological analysis was conducted through Most Probable Number (MPN) technique. The results highlighted that all the selected physicochemical parameters of tap water samples for the selected months were found within the permissible limits set by WHO and PSDWQ except DO, TDS, TSS, Free and total chlorine. DO, TSS and TDS were found exceeding the prescribed limits throughout the study, however detection of chlorine at consumer end (tap water) was almost negligible indicating poor disinfection system. The results of microbial analysis clearly forbid residents to drink tap water as high microbial loads were detected. As no residual chlorine was maintained till the consumer end it justifies high microbial load in tap water. Results conclude that improving water disinfection is highly recommended for maintaining public health.

Keywords: Drinking water distribution system (DWDS), Tap water quality, Physicochemical analysis, Bacteriological analysis, Contamination.

Introduction

Water is the utmost asset for the existence of life[1]. Life on earth depends upon water so much that water is called as "life"[2]. Water is an essential natural resource found on earth. It is vital for the proper functioning of ecological systems, living organisms, sound human health, economic development and production of food[3]. 70% of the surface of the earth is covered with water out of which most of it is salt water in the oceans and only 3% is freshwater which is considered safe for drinking, 97% of which is frozen in glaciers which highlights that we have <1% usable water from rivers, lakes and underground sources[4]. Potable water is described as water that does not contain any disease causing microorganisms and deadly chemicals that can degrade human health[5]. Before water is documented as potable it needs to satisfy certain chemical, physical and microbiological standards which are especially devised to confirm that whether water is potable, safe and clean for drinking or not[4].

Water is considered as a passive carrier for diverse organisms such as bacteria, viruses and protozoa which can cause multiple illnesses in humans. The existence of indicator organism in water is considered a key factor in determining the health issues caused by pathogens. Presently *E. coli* is considered as a perfect fecal indicator bacterium for the monitoring of fecal contamination around the globe in drinking water quality regulations and guidelines. According to WHO, the presence of indicator organisms in drinking water should be non-detectable in a 100ml sample[6]. Chlorination is a traditional method to purify and decontaminate drinking water supplies and coliform populations. But studies have revealed that potable water free of coliforms may not be free from harmful human pathogens that can lead to waterborne diseases[7].

Access to safe and clean drinking water is a fundamental right and vital necessity of every human being on earth and represents one of the most crucial factors of civilization[8,9]. Persistent advancements in the quality of water for the intention of drinking, personal hygiene, domestic consumption and some medical situations is amid the leading challenges of the world[10]. According to a Joint Monitoring Programme (JMP) for sanitation and water supply conducted by UNICEF and WHO reported that around the globe 783 million people unfortunately have no access to clean and safe water, about 84% of them were found to live in rural areas[11]. More than 5 million people in the world die every year from diseases caused by drinking water related to inadequate sanitation[7]. Most of the people that have no access to sanitation facilities and safe and clean drinking water, belong to the developing countries of Asia and Africa[4]. Water is not only crucial for life, but it also acts as a vehicle in transmitting numerous diseases in humans[12]. It has been estimated that 75% of waterborne diseases in the world are a result of failure to obtain safe and clean drinking water[8]. Waterborne diseases such as intestinal infections (giardiasis, gastro-enteritis, etc.), cholera, diarrhea, dysentery, vomiting, typhoid fever, numerous skin diseases, neurological disorders, reproductive problems, shigellosis and various other illnesses are found most common in older people and children thus leading to an increase in morbidity and mortality[6,8,10]. Existence of toxic heavy metals such as nitrate, arsenic etc. in water can cause fatal waterborne diseases like hepatitis and cancer[3]. It is reported that waterborne diseases such as cholera, typhoid fever, amoebic and bacillary dysentery causes the death of about 3.4 million people over the world every year[5]. Diarrhea is the leading waterborne disease which causes more than 2 million deaths all over the world every year, most affected are the children, age below 5 years[13]. It is thus essential that the water which is to be used for human consumption should be free from toxic chemicals and disease causing germs in order to protect public health[14].

Pakistan a developing country is facing a serious problem with the reference to the quality of drinking water[6]. Only 25% of population in Pakistan has continual access to clean and safe drinking water. Due to the manipulation of many external elements in Pakistan, its groundwater quality is no longer safe. Aging and rusty pipelines carrying drinking water in Pakistan poses a deadly threat to the water natural composition. Due to unsatisfactory treatment practices, technologies, poor institutional arrangements, absence of well-equipped laboratories and efficient monitoring plans this problem has become more critical[15,16]. According to a report by International Union on Conservation of Nature (IUCN) it was estimated that 60% of infants in Pakistan die as a result of waterborne diarrhea which is the greatest in Asia[15]. Researchers have concluded that each year in Pakistan more than 3 million people fall victim to waterborne diseases out of which 0.1 million die[16]. 70% of people live in rural areas of Pakistan have no access to clean and safe drinking water. Water quality of Pakistan is found to be at a threat from increase in urbanization as it has reduced the access to clean and safe drinking water from 60% to 40% respectively. In Pakistan treatment and filtration of water is usually not conducted before the supply of water for drinking purposes[17]. The solution to sustainable water resources is to confirm that the water quality is appropriate for its expected uses, whereas at the same time enabling them to be utilized and evolved to a certain degree[18]. The goal of this study was to evaluate the physico-chemical and bacteriological quality of drinking tap water.

Methodology

Site Description: The present study was undertaken in a residential university of Pakistan namely National University of Sciences and Technology (NUST). It was founded in 1991 while its new campus which is located in the capital of the country, Islamabad was recognized in 2008. It is a public sector research university. NUST is stretched across a massive area of 707 acres, it has more than 15 schools and institutes, male and female hostels as well as faculty residence. Ground water sources feed the NUST water distribution system. Water is pumped through 9 tube wells and then transported to 3 underground storage tanks or 2 overhead reservoirs. Tube wells have a pumping capacity of 0.2 million gallons per day (MGD) which serve a population of around 11400 people. Water in these storage tanks are either supplied directly to the DWDS or stored overnight in overhead reservoirs with storage time of 2-3 days.

Sampling Sites: For the analysis of drinking water quality of NUST, initial examination of raw and chlorinated water at the storage tanks was carried out. NUST is divided into three zones, each zone contains particular number of institutes (departments). Each zone is supplied water from one of the three storage tanks. Raw water in storage tanks and water after chlorination was examined (Ten physicochemical properties: pH, Electrical conductivity, Dissolved oxygen, Alkalinity, Hardness, Total organic carbon, Total dissolved solids, Total suspended solids, Turbidity, Free and total chlorine. Bacteriological property: Most probable number technique). The results of raw and chlorinated water indicated that zone 1 was the most contaminated zone of the three due to low chlorine detection and high bacterial contamination (Results of initial examination are not mentioned here, it was conducted to select sampling sites). Therefore zone 1 was selected for drinking water quality analysis. Six institutes (departments) were randomly selected from zone 1 for water quality analysis of tap water. After the selection of sampling stations for water quality analysis, tap water was obtained from the kitchens of the selected sampling stations. Whereas those stations which do not have kitchens, tap water was obtained from toilets as shown in Table-1.

Table-1: Selected sampling stations.

Sampling Station	Detail	Sampling Location
S1	Iqra-Apartment	Kitchen (Tap water)
S2	Fatima Hostel	Toilet (Tap water)
S3	Institute of Environmental Science and Engineering	Kitchen (Tap water)
S4	School of Chemical & Material Engineering	Kitchen (Tap water)
S5	Atta-ur-Rehman School of Applied Biosciences	Kitchen (Tap water)
S6	Institute of Geographical Information System	Toilet (Tap water)

Tap water was obtained from 6 sampling stations in a period of 4 months (November 2019, December 2019, January 2020 and February 2020) respectively to evaluate variations in water quality. Ten physicochemical properties pH, Dissolved oxygen (DO), Electrical conductivity (EC), Chlorine (free and total), Turbidity, Total organic carbon (TOC), Hardness, Alkalinity, Total suspended solids (TSS) and Total dissolved solids (TDS). Microbial analysis was conducted through the Most Probable Number Technique (MPN).

Sampling: The water samples were collected from the selected sites in 500ml sterilized Schott bottles according to WHO guidelines to access the physicochemical and bacteriological quality of tap water. Samples were collected carefully to avoid any sort of contamination. The tap water was allowed to run for 3-4 minutes before obtaining the sample. The water samples were than stored in an ice box and transferred to laboratory for analysis. After the collection of samples, they were analyzed immediately or within 1 hour of their collection or they were stored in refrigerator and analyzed within 4 hours of their collection. Triplicate water samples were taken and monitored for result validation. All the collection, transportation and storage procedures were carried out as prescribed in the Standard Methods for the Examination of Water and Wastewater[19].

Physicochemical Properties: Accessing the quality of drinking water is of utmost importance for the well-being of individuals consuming it. From the selected physicochemical parameters some were measured onsite as they may change with time like, pH (HACH 156 pH meter), Dissolved oxygen (Crison Oxi 45 DO meter), Electrical conductivity (Conductivity meter 3210), Free and total chlorine (Hanna HI 96734 chlorimeter). The rest of the physicochemical parameters were measured in laboratory like, Turbidity (Turbidimeter HACH 2100P), Hardness and Alkalinity (Titration), Total dissolved and suspended solids (gravimetric method). Formula given by Adams et al.[20] was used to determine TOC.

$$\text{Organic carbon (\%)} = \frac{\text{VS (\%TS)}}{1.8}.$$

The results of TOC were converted into mg/L for drinking water. Analyses of all the parameters were performed as per the Standard Methods for the Examination of Water and Wastewater[19].

Bacteriological Properties: For bacteriological analysis the water samples were instantly analyzed after collection for the existence of total and fecal coliforms and E. coli (bacterial indicator). Most Probable Number Technique (MPN) was used which involves three phases. In the presumptive phase, 10 fermentation test tubes each one of them containing 10ml Laural Tryptose Broth **(**LTB) and an inverted durham tube were used. After a strong shake, 10ml of the sample was added to each tube. The tubes were then placed in incubator at 37ºC for 24 hours. Formation of gas and turbidity in the tubes showed a positive presumptive reaction and thus gave evidence for the existence of total coliforms.

Positive tubes were further put through confirmation phase. Positive LTB tubes were shaken slightly and a small inoculum using wire loop was transferred to Brilliant Green Bile Broth (BGLB) tubes. BGLB tubes were then placed in an incubator at 37ºC for 24 hours. Formation of gas and turbidity after 24 hours in BGLB tubes proved the existence of total coliforms.

Positive tubes from earlier phase were taken and headed towards the completed phase for fecal coliforms, after gently shaking, a small amount using wire loop was added to *Escherichia coli* (EC) broth tubes and incubated at 37ºC for 24 hours. Formation of gas and turbidity proved the presence of fecal coliforms (*E.coli*)[19].

Results and discussion

The results of physicochemical and bacteriological analysis of drinking tap water were compared with World Health Organization (WHO) guidelines and Pakistan Standards for Drinking Water Quality (PSDWQ). Table-2 shows the standard values of those parameters as prescribed by WHO and PSDWQ.

Table-2: Standard values for drinking water quality.

Water quality parameters	Standard values	
	WHO[21]	PSDWQ[22]
pH	6.5-8.5	6.5-8.5
Dissolved Oxygen (mg/L)	6-8	---
Electrical Conductivity (μS/cm)	2500	---
Free & Total Chlorine (mg/L)	0.2-0.5	*
Turbidity (NTU)	<5	<5
Total Organic Carbon	---	---
Hardness (mg/L)	<500	<500
Alkalinity (mg/L)	<500	<500
Total Dissolved Solids (mg/L)	<1000	<1000
Total Suspended Solids (mg/L)	5	---
MPN /100ml	0/100	0/100

*Residual chlorine at source= 0.5-1.5mg/L and at consumer end 0.2-0.5mg/L.

Physicochemical Analysis: pH: pH is a word which is globally used to demonstrate the alkaline and acidic condition of a solution[23]. Changes in temperature can bring changes in pH[1]. The pH of water is immensely important, as any fluctuations in optimum pH can result in an increase or decrease in the toxic nature of poisons in water bodies[5]. In this study the pH of tap water in the month of November among the six locations ranged from 7.66-7.79 respectively. In November lowest pH of 7.66 was observed in the tap water of S2. The highest pH of 7.79 was observed in the tap water of S6. pH of tap water in the month of December ranged from 7.33-7.67 among the six locations respectively where in December lowest pH of 7.33 was observed in the tap water of S6 and highest of 7.67 was observed in the tap water of S5. pH of tap water in the month of January among the six locations ranged from 7.38-7.56 respectively. In January lowest pH of 7.38 was observed in the tap water of S2 and highest pH of 7.56 was observed in the tap water of S3 and S4. In February the value of tap water pH among the six locations ranged from 7.25-7.49 respectively where in February lowest pH of 7.25 was observed in the tap water of S1 and highest pH of 7.49 was observed in the tap water of S6.

The value of tap water pH for all the six locations were found to vary from month to month indicating that pH of water changes with temperature. Overall the tap water pH of all the six locations were found to slightly decrease (fluctuate) from November to February and became more close towards neutral. They were found within the required limits set by WHO and PSDWQ which are 6.5-8.5 as shown in Figure-1. According to a related study conducted by Amin et al.[17] physicochemical properties of water distribution network of 10 locations in Peshawar, Pakistan were assessed, the pH was found in the range of 6.71-8.21 with a mean of 7.33 which was also found within the permissible limit set by WHO and PSDWQ. Similarly in a study carried out by Akhtar et al.[8] pH of tap water in Mianwali, Pakistan were assessed (230 samples) having a mean value of 7.5 which was also found within the acceptable range. Ahmed et al.[24] examined the drinking water quality of primary schools of Sindh province in Pakistan, the average pH values were found between 7-8 which were also within the recommended limits.

Dissolved Oxygen (DO): In water dissolved oxygen is a major parameter to test water quality, it gives a reflection of biological and physical processes taking place in the water[23]. DO gives the estimate of the degree of pollution in water, lower the value of DO the greater the concentration of pollution in water[3]. In this study the DO of tap water in the month of November among the six locations ranged from 8.3-9mg/L respectively. In November lowest DO of 8.3mg/L was found in the tap water of S5 and highest DO of 9mg/L was found in the tap water of S6. In December the value of tap water DO among the six locations were found in the range of 9.5-10.1mg/L respectively. The lowest value of DO in December was 9.5mg/L which was observed in the tap water of S1 whereas the highest DO of 10.1mg/L was observed in the tap water of S4, S5 and S6. In the month of January the values of tap water DO among the six locations ranged from 10.2-10.6mg/L respectively. The lowest value of DO in January was 10.2mg/L which was observed in the tap water of S1 and S5. The highest DO of 10.6mg/L was observed in the tap water of S3, S4 and S6. In February the value of tap water DO among the six locations was in the range of 10-10.3mg/L respectively. The lowest value of DO in February was 10mg/L which was observed in the tap water of S1 and S2. The highest value of DO in February was 10.3mg/L which was observed in the tap water of S3.

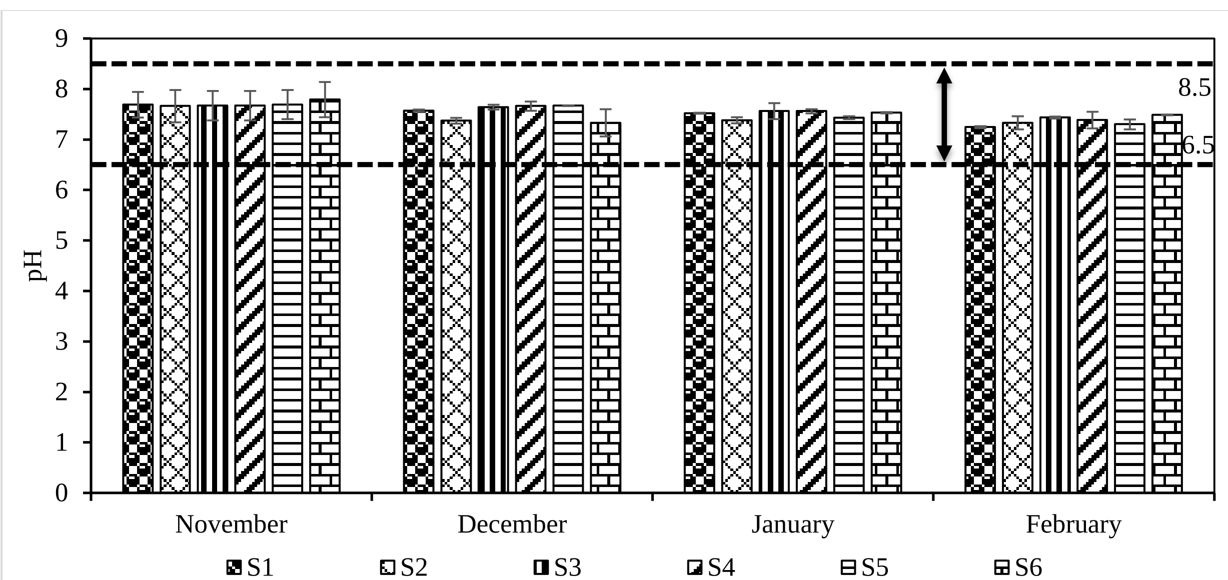

Figure-1: Temporal variation in pH profiles of tap water from selected sampling stations. Dash line indicates the range of WHO standard[21] and PSDWQ[22].

The tap water DO for all the six locations varies from month to month. The tap water DO of all the six locations in every selected month (November, December, January and February) was found to exceed the permissible limits set by WHO which is 6-8mg/L as shown in Figure-2. The trend shows that in the month of November the tap water DO is slightly higher than the recommended limit, than it further increases in December and January and then it slightly falls down in February, but is still above the recommended limit. DO has an inverse relation with temperature, when there are low temperatures high values of DO are observed, whereas it is opposite for high temperature. As the selected months for investigation cover the winter season this confirms why greater values of DO are observed. The slight fall in February could be due to microbial activity and organic decay.

Electrical Conductivity (EC): Electrical conductivity measures the capacity of water to carry electrical current through it[9]. Water having high EC specifies that the water contains high amount of TDS[17]. In this study tap water EC in the month of November among the six locations ranged from 852-882.5µS/cm respectively. The lowest value of EC in the month of November was 852µS/cm which was observed in the tap water of S4, whereas the highest value of EC observed was 882.5µS/cm in the tap water of S3. The EC of tap water among the six locations in the month of December were found in the range of 807-887µS/cm respectively. Lowest value of EC in the month of December was 807µS/cm which was found in the tap water of S2 whereas highest value of EC was 887µS/cm in December which was found in the tap water of S1. In the month of January the tap water EC among the six locations were in the range of 917-950µS/cm respectively. The lowest value of EC in the month of January was 917µS/cm which was observed in the tap water of S2. The highest value of EC in January was 950µS/cm which was observed in tap water of S3. The tap water EC in the month of February among the six locations was in the range of 878.5-929µS/cm. The lowest value of EC observed in February was 878.5µS/cm which was found in the tap water of S2. The highest value of EC observed in February was 929µS/cm which was found in the tap water of S1.

The tap water EC for all the six locations varies from month to month. But the tap water EC of all the six locations in every selected month was found in the limit set by WHO which is 2500µS/cm as shown in Figure-3. The trend indicates that the values of tap water EC in November and December remain almost constant, than in January their values increased slightly but were within the limits, than slightly falls down in February. According to a similar study by Amin et al.[17] EC of water samples from 10 different water distribution systems in Peshawar were found in the range of 519-881µS/cm with a mean of 667.1µS/cm which were also found within the permissible limits set by WHO. Related study by Yasin et al.[13] in Jimma zone, Southwest Ethiopia where the EC of tap water was found to be 366.9µS/cm which was far below the values obtained in our study. The possible reason of high conductivity values of water in the present research could be due to the corrosion of metals (pipes) which can also lead towards the accumulation of heavy metals in water.

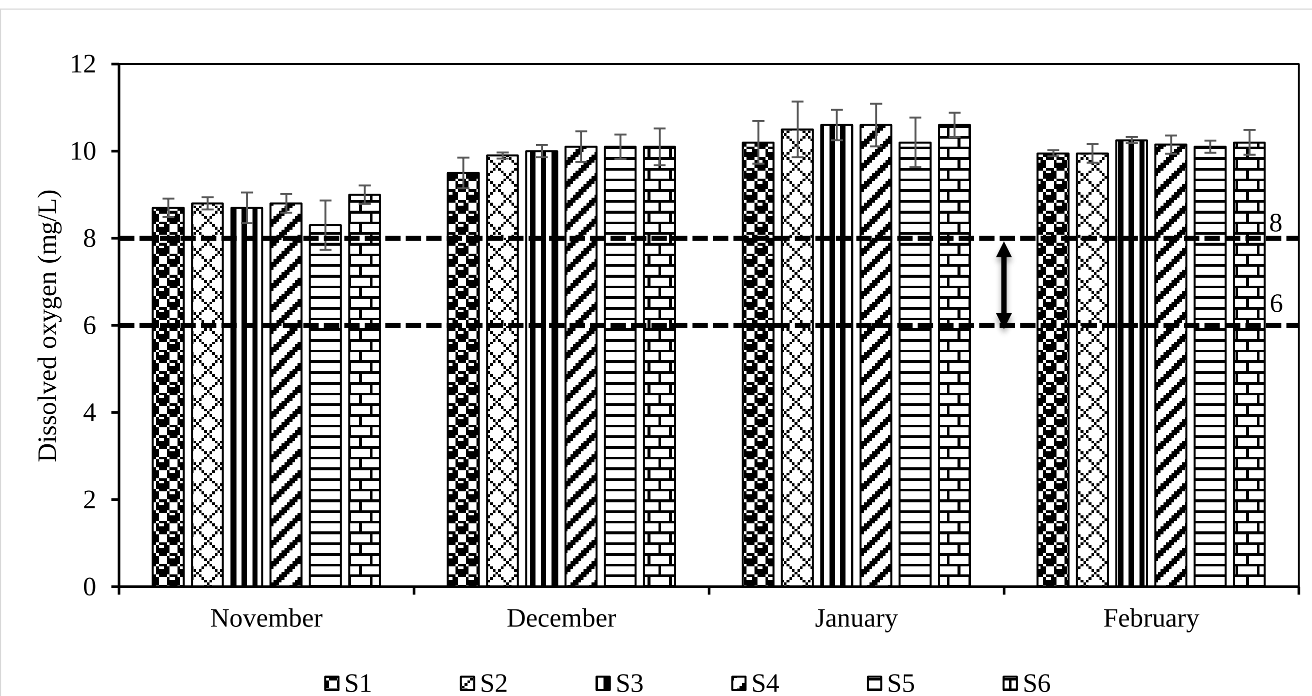

Figure-2: Temporal variation in DO profiles of tap water from selected sampling stations. Dash line indicates the range of WHO standard[21].

Chlorine (Free & Total): Chlorine is an effective disinfectant in eliminating viruses and pathogenic bacteria[25]. In this study the value of tap water free chlorine in the month of November among six locations were found in the range of 0-0.04mg/L respectively. The lowest value of free chlorine observed in November was 0mg/L (free chlorine not detected) in the tap water of S1, S3, S4 and S5, whereas the highest value of free chlorine observed in November was 0.04mg/L which was found in the tap water of S2. In December the value of tap water free chlorine among the six locations were found in the range of 0-0.25mg/L respectively. The lowest value of free chlorine observed in December was 0mg/L (free chlorine not detected) in the tap water of S4. The highest value of free chlorine observed in December was 0.25mg/L which was found in the tap water of S1. In the month of January the value of tap water free chlorine among the six locations ranged from 0-0.03mg/L respectively. The lowest value of free chlorine observed in January was 0mg/L (free chlorine no detected) in the tap water of S3 and S4, whereas the highest value of free chlorine observed in January was 0.03mg/L in the tap water of S5 and S6. The value of tap water, free chlorine in the month of February among the six locations was found in the range of 0-0.02mg/L respectively. The lowest value of free chlorine observed in February was 0mg/L (free chlorine not detected) in the tap water of S1, S2, S3, S4 and S5, whereas the highest value of free chlorine observed in month of February was 0.02mg/L in the tap water of S6. By examining the trend in Figure-4 it was observed that there was almost negligible free chlorine in the month of February.

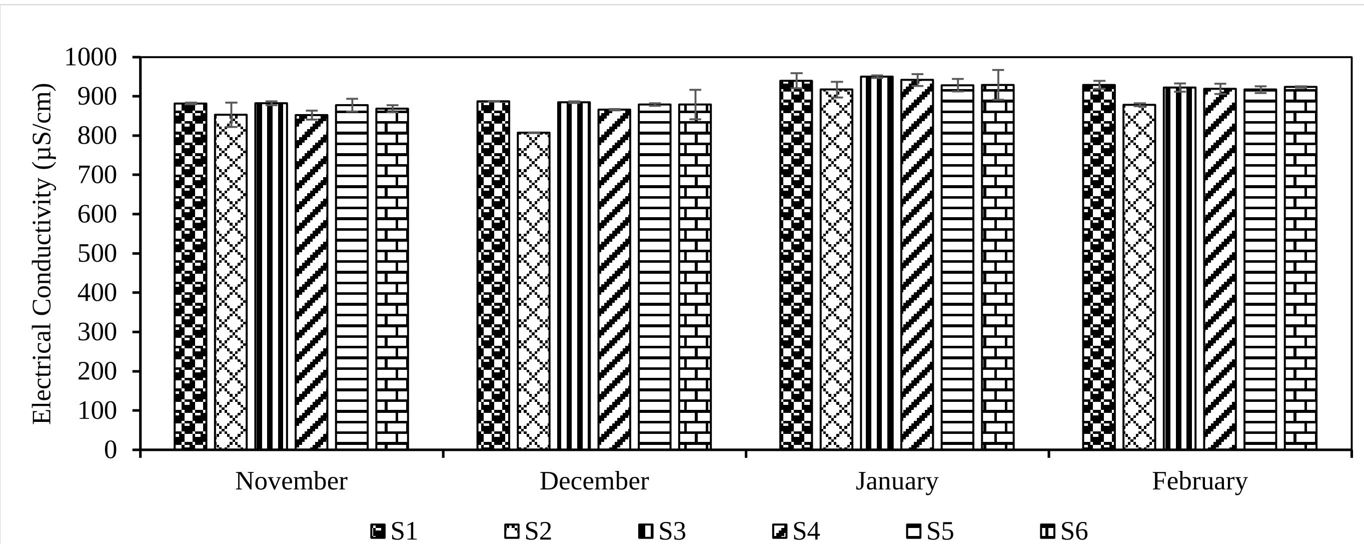

Figure-3: Temporal variation in EC profiles of tap water from selected sampling stations.

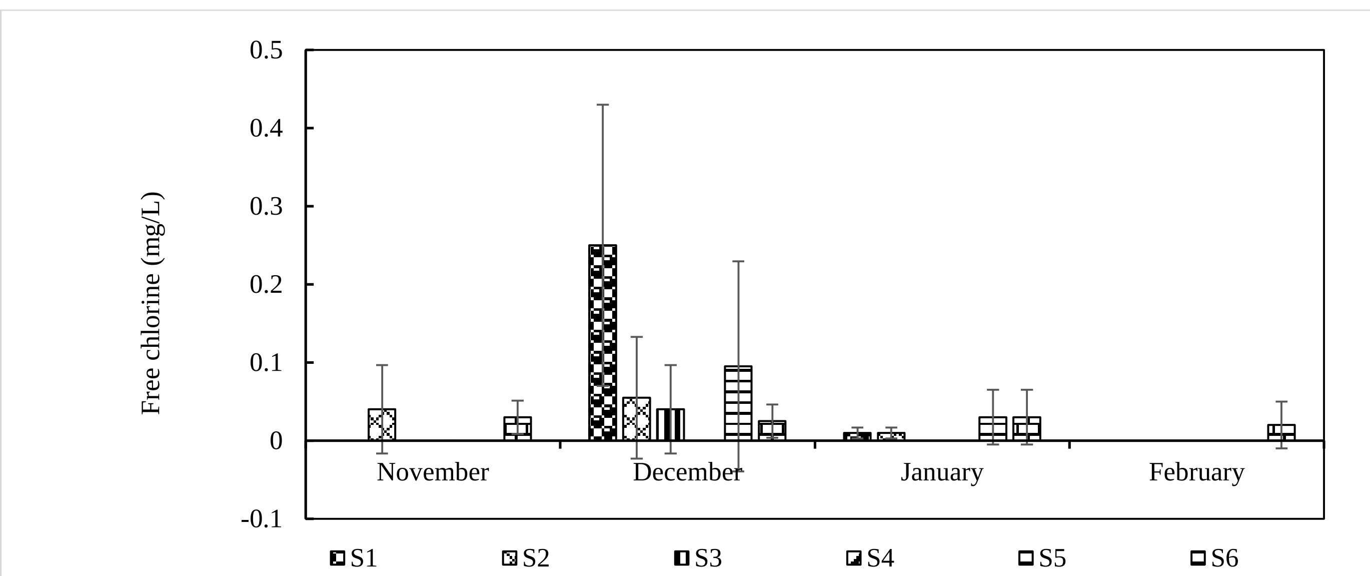

Figure-4: Temporal variation in free chlorine profiles of tap water from selected sampling stations.

In the present study the value of tap water total chlorine in the month of November among the six locations were found in the range of 0.19-0.37mg/L respectively. Where the lowest value of total chlorine observed in November was 0.19mg/L found in the tap water of S2 and S3. The highest value of total chlorine observed in November was 0.37mg/L which was found in the tap water of S1. In December the value of tap water total chlorine among the six locations were found in the range of 0.19-0.5mg/L respectively. The lowest value of total chlorine observed in the month of December was 0.19mg/L in the tap water of S3, whereas the highest value of total chlorine observed in December was 0.5mg/L in the tap water of S1. In the month of January the tap water total chlorine among six locations ranged from 0.03-0.05mg/L respectively, where the lowest value of total chlorine observed in January was 0.03mg/L in the tap water of S5 and the highest value of total chlorine observed in January was 0.05mg/L in the tap water of S2, S3 and S6. The tap water total chlorine for the month of February among the six locations ranged from 0-0.14mg/L respectively. The lowest value of total chlorine observed in February was 0mg/L (total chlorine not detected) in the tap water of S5, whereas the highest value of total chlorine observed in February was 0.14mg/L in the tap water of S3. By examining the trend in Figure-5 it was observed that there was a huge decrease in the amount of total chlorine in the months of January and February.

The tap water free and total chlorine for all the six locations varies from month to month. According to WHO and PSDWQ the amount of chlorine at source should be in range of 0.5-1.5mg/L and at consumer end residual chlorine should be in a range of 0.2-0.5mg/L for maximum disinfection and purification of drinking water. However in the current study the amount of free chlorine at consumer end at many selected locations in selected months were negligible and locations where residual chlorine was detected except S1 in December was far below the recommended limit thus highlighting that the drinking water at these locations during the selected months will be loaded with microbes and thus not suitable for drinking. Reason is derived from the previous initial study on the raw and chlorinated water which concluded that far less amount of chlorine required for chlorination was being used. A related study conducted by Clasen et al.[26] found zero residual chlorine at the sampling points while examining drinking water at consumer ends in India's 14 major urban centers.

Turbidity: Turbidity is the amount of solid suspended particles present in water[27]. In this study tap water turbidity in the month of November among the six locations was in the range of 0.55-1.49 NTU respectively. The lowest value of turbidity observed in November was 0.55 NTU which was found in the tap water of S4, whereas the highest value of turbidity observed in November was 1.49 NTU which was found in the tap water S2. In the month of December the value of tap water turbidity among the six locations ranged from 0.57-2.15 NTU respectively. The lowest value of turbidity observed in December was 0.57 NTU which was found in the tap water of S6. The highest value of turbidity observed in December was 2.15 NTU which was examined in the tap water of S1. The turbidity of tap water in the month of January among the six locations was found in the range of 0.73-1.19 NTU respectively. The lowest value of tap water turbidity observed in January was 0.73 NTU which was found in the tap water of S5, whereas the highest value of tap water turbidity observed in January was 1.19 NTU which was found in the tap water of S2. In the month of February the tap water turbidity among the six locations was found in the range of 0.71-0.89 NTU respectively. The lowest value of turbidity observed in February was 0.71 NTU which was found in the tap water of S2. The highest value of turbidity observed in February was 0.89 NTU which was found in the tap water of S6.

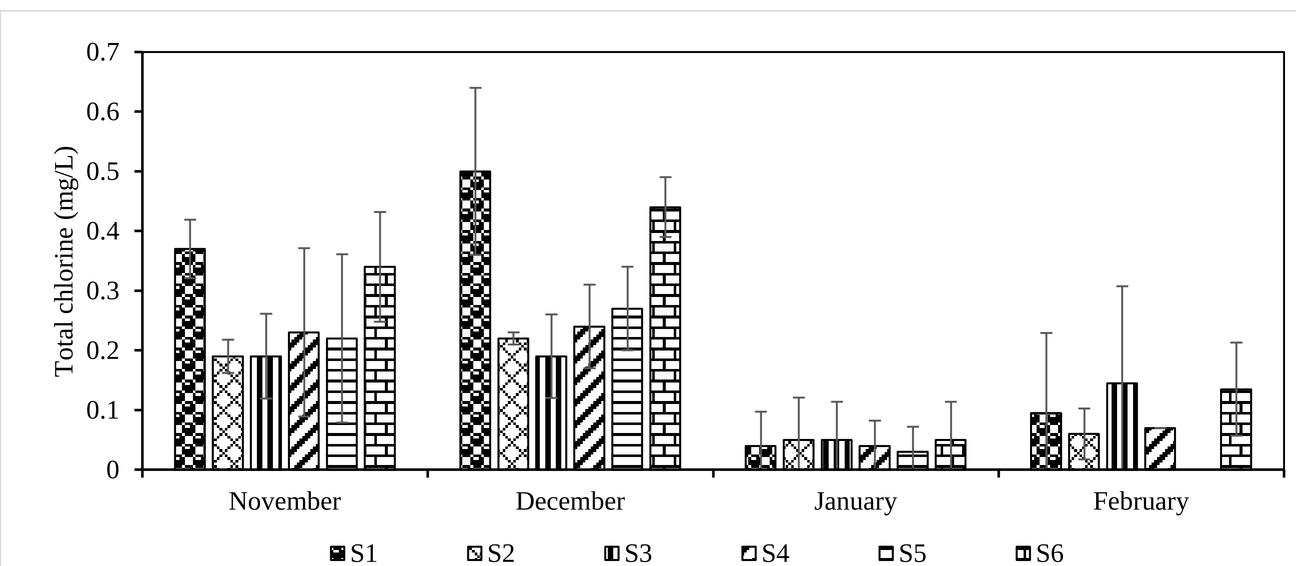

Figure-5: Temporal variation in total chlorine profiles of tap water from selected sampling stations.

The tap water turbidity for all the six locations varies from month to month. The tap water turbidity of all the six locations in every selected month was found in the limit prescribed by WHO and PSDWQ which is <5NTU as shown in the Figure 6. In the month of November the value of turbidity in S2 and in December the value of turbidity in S1 was quite high as compare to other selected locations and months but they were within the required limits set by WHO and PSDWQ the only possible reason could be leakage in distribution network or increased corrosion of pipes leading to increased amount of particulate matter in water. Though the levels of turbidity were found within the permissible standards but were more than the value recommended for effective disinfection which is 0.5NTU. According to a related study carried out by Lina et al.[10] physicochemical properties of tap water obtained from five locations in Bidar District of India were assessed, turbidity was found in the range of 0.5-2.85NTU which were also within the permissible limits set by WHO. A related study carried out by Meride and Ayenew[27] assessed the quality of drinking water supplied to the residents of Wondo genet campus Ethiopia. The mean value of turbidity obtained was 0.98NTU which was also within the set limits. Water with high levels of turbidity is loaded with pathogenic microorganisms making the water contaminated and not suitable for consumption.

Total Organic Carbon (TOC): Total organic carbon is mostly regarded as a non-specific indicator of water quality[28]. In this study the TOC of tap water in the month of November among the six locations was in the range of 0.08-0.19mg/L respectively. The lowest value of TOC observed in the month of November was 0.08mg/L which was found in the tap water of S3 and S4, whereas the highest value of TOC observed in November was 0.19mg/L which was found in the tap water of S2. In the month of December the value of TOC in tap water among the six locations was in the range 0.07-0.16mg/L respectively. The lowest value of TOC observed in December was 0.07mg/L which was found in the tap water of S5. The highest value of TOC observed in December was 0.16mg/L which was found in the tap water of S2 and S6. The value of tap water TOC found in the month of January among the six locations was in the range of 0.08-0.15mg/L respectively. Where in January the lowest value of TOC observed was 0.08mg/L in the tap water of S5. The highest value of TOC observed in January was 0.15mg/L which was found in the tap water of S2. In February the value of tap water TOC among the six locations was found in the range of 0.23-0.32mg/L respectively. The lowest value of TOC observed in February was 0.23mg/L in the tap water of S2, whereas the highest value of TOC observed in February was 0.32mg/L in the tap water of S4, as shown in Figure-7. The Figure-7 illustrates that the amount of TOC in tap water in November, December and January varies slightly from each other but the amount of TOC in February was raised considerably. The possible reason could be increased decay of natural organic matter or bacterial growth.

Hardness: Salts of calcium and magnesium are responsible for hardness in water[1]. In this study the value of tap water hardness in the month of November among the six locations were found in the range of 313-371mg/L respectively. The lowest value of hardness observed in the month of November was 313mg/L in the tap water of S4, whereas the highest value of hardness observed in November was 371mg/L in the tap water of S3. In December the value of tap water hardness among the six locations were found in the range of 329-417mg/L respectively. The lowest value of hardness observed in December was 329mg/L in the tap water of S2. The highest value of hardness observed in December was 417mg/L which was found in the tap water of S3. Tap water hardness in the month of January among the six locations was found in the range of 329-380mg/L respectively. The lowest value of hardness observed in January was 329mg/L in the tap water of S2, whereas the highest value of hardness observed in January was 380mg/L in the tap water of S1. In February the value of tap water hardness among six locations were found in the range of 341-374mg/L respectively. The lowest value of hardness observed in February was 341mg/L in the tap water S2. The highest value of hardness observed in February was 374mg/L in the tap water of S6.

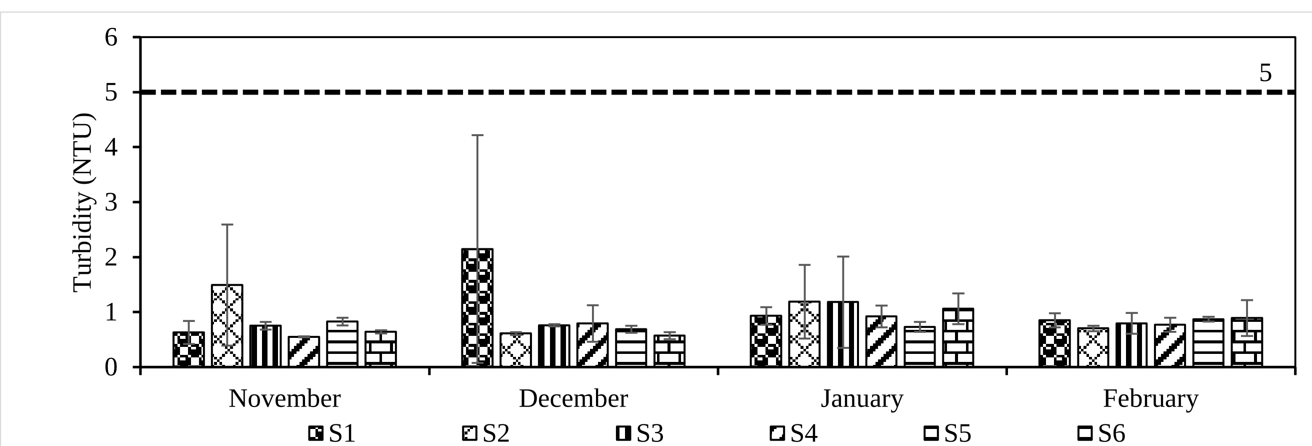

Figure-6: Temporal variation in turbidity profiles of tap water from selected sampling stations. Dash line indicates the WHO standard[21] and PSDWQ[22].

The tap water hardness for all the six locations varies from month to month. But the tap water hardness of all the six locations in every selected month was found in the limit set by WHO which is <500mg/L respectively as shown in Figure-8, thus suggesting that the water is soft. According to a similar study performed by Sailaja et al.[23] in which he assessed the physicochemical properties of tap water of 37 wards in Kavali Municipality, SPSR Nellore district, India. The mean value of hardness 125mg/L was also found within the permissible limits. A related study conducted by Haydar et al.[16] in which drinking water quality of Southern Lahore, Pakistan was assessed before and after monsoon. Hardness of water samples were found to range from 117-230mg/L as $CaCO_3$ before monsoon and 130-333mg/L after monsoon, hardness of water both before and after monsoon was found within the permissible limit.

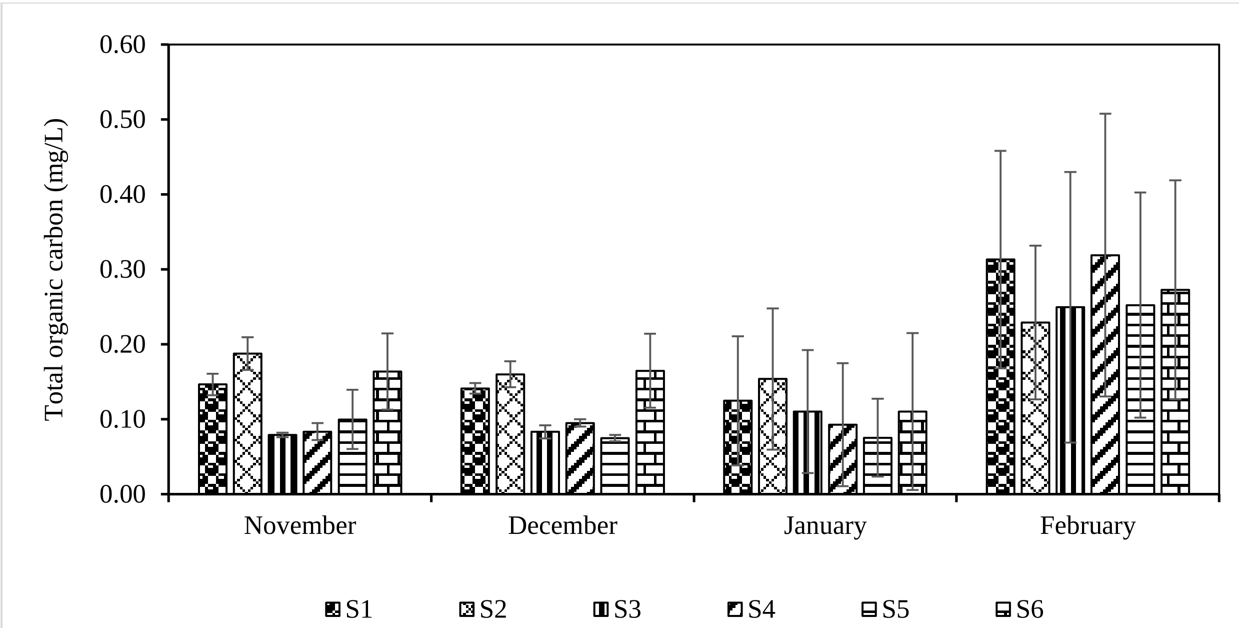

Figure-7: Temporal variation in TOC profiles of tap water from selected sampling stations.

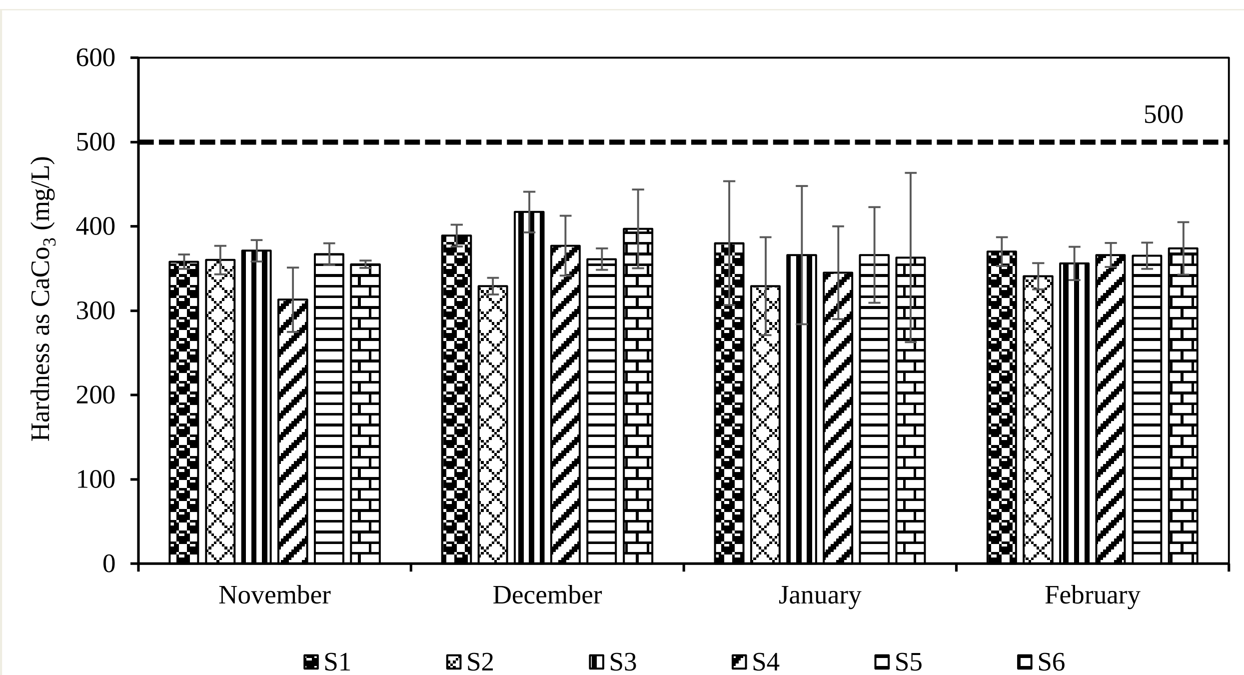

Figure-8: Temporal variation in hardness profiles of tap water from selected sampling stations. Dash line indicates the WHO standard[21] and PSDWQ[22].

Alkalinity: The capacity of water to withstand fluctuations in pH when an acid is added to it is described as the total alkalinity of water[29]. In this study the value of tap water alkalinity in the month of November among the six locations were found in the range of 398-461mg/L respectively. The lowest value of alkalinity observed in the month of November was 398mg/L in the tap water of S4. The highest value of alkalinity observed in November was 461mg/L in the tap water of S5. In December the value of tap water alkalinity among the six locations ranged from 364-423mg/L respectively. The lowest value of alkalinity observed was 364mg/L which was found in the tap water of S2, whereas the highest value of alkalinity observed in December was 423mg/L in the tap water of S1. The value of tap water alkalinity observed in the month of January among the six locations was found in the range of 417-501mg/L respectively. The lowest value of alkalinity observed in January was 417mg/L in the tap water of S5. The highest value of alkalinity observed in January was 501mg/L which was found in the tap water of S1. In February the value of tap water alkalinity among the six locations were found in the range of 404-450mg/L respectively. The lowest value of alkalinity observed in February was 404mg/L which was found in the tap water of S2, whereas the highest value of alkalinity observed in February was 450mg/L in the tap water of S6.

The tap water alkalinities for all the six locations vary from month to month. Apart from the value of alkalinity (501mg/L) observed in the tap water of S1 in January, the alkalinity of tap water in all the six locations in every selected month was found within the limits prescribed by WHO and PSDWQ which is <500mg/L as shown in Figure-9 respectively. The overall possible reason for variations in tap water alkalinity including the highest alkalinity of 501mg/L in S1 in January could be explained by human activities like the processes involved in water treatment before water is discharged to consumers could slightly modify alkalinity in drinking water. According to a similar study carried out by Bhardwaj and Giri[2] in which physicochemical properties of tap water from Indora, Himachal Pradesh, India was assessed. The mean value of alkalinity was calculated to be 285.17mg/L which was also within the set permissible limit. Related study carried out by Sailaja et al.[23] assessed the alkalinity of tap water of 37 wards of Kavali Municipality, SPSR Nellore district, India. The mean alkalinity was 120mg/L, which was also within the set permissible limit by WHO thus supporting the present study.

Total Dissolved Solids (TDS): Inorganic salts and meager amount of organic matter dissolved in water give us total dissolved solids[3]. In this study the value of tap water TDS in the month of November among the six locations were found in the range of 488-642mg/L respectively. The lowest value of TDS observed in November was 488mg/L in the tap water of S4, whereas the highest value of TDS observed in November was 642mg/L in the tap water of S6. In December the value of TDS observed among the six locations were found in the range of 631-797mg/L respectively. The lowest value of TDS observed in December was 631mg/L which was found in the tap water S4. The highest value of TDS observed in December was 797mg/L in the tap water of S2. The value of tap water TDS observed in the month of January among the six locations were found in the range of 595-705mg/L respectively. The lowest value of TDS observed in January was 595mg/L in the tap water of S5 and the highest value of TDS observed in January was 705mg/L in the tap water of S6. In February the value of tap water TDS among the six locations were found in the range of 910-1080mg/L respectively. The lowest value of TDS observed in February was 910mg/L which was found in the tap water S5, whereas the highest value of TDS observed in February was 1080mg/L in the tap water of S1.

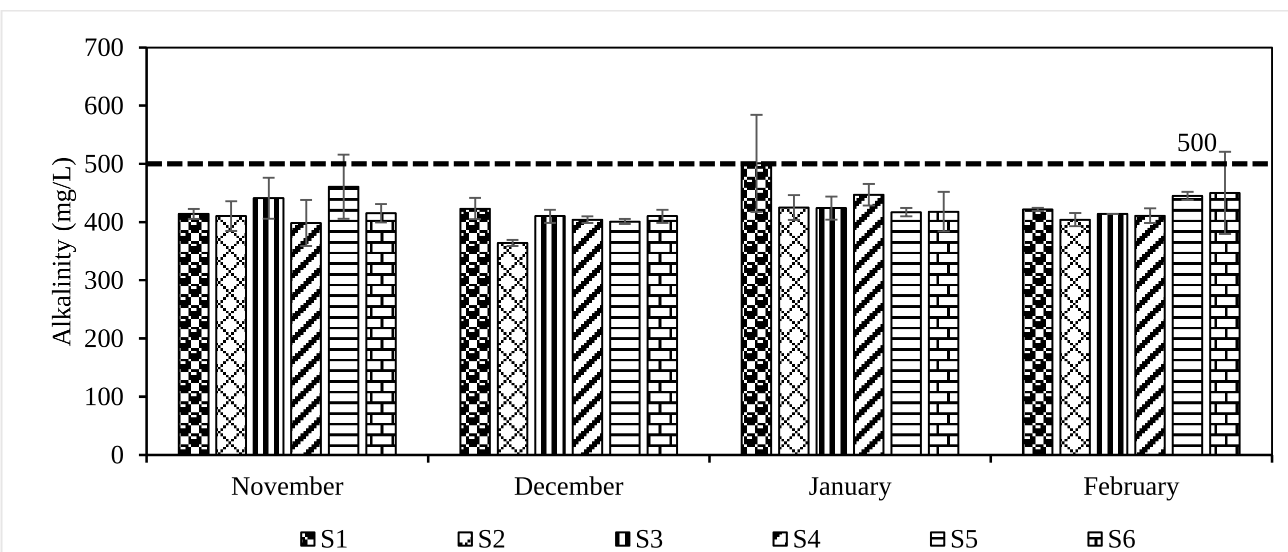

Figure-9: Temporal variation in alkalinity profiles of tap water from selected sampling stations. Dash line indicates the WHO standard[21] and PSDWQ[22].

The tap water TDS for all the six locations varies from month to month. Apart from the value of TDS (1055mg/L in S6 and 1080mg/L in S1) in the month of February, the TDS of tap water in all the six locations in every selected month was found within the limits prescribed by WHO and PSDWQ which are <1000mg/L as shown in Figure-10 respectively, as TDS <1000mg/L is considered acceptable for drinking purposes. By looking at the trend of TDS in Figure-10, it is quite visible that the concentration of TDS in the tap water of six locations have increased rapidly in the month of February where the tap water of S1 and S6 have crossed the prescribed limit by WHO and PSDWQ. Cemented storage tanks used to store water before distribution and corrosion of metallic pipes are found to be the only possible reason for increase in the amount of TDS in water.

A related study conducted by Lina et al.[10] the amount of TDS in the tap water of Bidar, district, India was evaluated and found to be in the range of 437.81-517.53mg/L respectively which was also within the prescribed WHO limits. Another related study carried out by Ikhlaq et al.[30] the amount of TDS in the drinking water of East-Lahore, Pakistan was assessed and was also found within the acceptable limit (288.63-782.7mg/L) thus supporting the present study. It was reported by WHO (1996) that water having TDS greater than 500mg/L can cause extreme scaling in distribution pipelines[1].

Total Suspended Solids (TSS): Total suspended solids are basically insoluble solids that either float or are present in the form of suspension thus causing turbidity[3]. In this study the value of tap water TSS in the month of November among the six locations were found in the range of 0-10mg/L respectively. The lowest value of TSS observed in the November was 0mg/L (TSS not detected) in the tap water of S1, S3, S4, S5 and S6, whereas the highest value of TSS observed in November was 10mg/L in the tap water of S2. In December the TSS of tap water observed among six locations ranged from 0-11mg/L respectively. The lowest value of TSS observed in December was 0mg/L (TSS not detected) in the tap water of S2 and S3. The highest value of TSS observed in December was 11mg/L in the tap water of S1. The value of tap water TSS in the month of January among the six locations were found in the of 0-20mg/L respectively. The lowest value of TSS observed in January was 0mg/L (TSS not detected) in the tap water of S2 and S3, whereas the highest value of TSS observed in January was 20mg/L in the tap water of S1 and S6. In February the value of tap water TSS among the six locations ranged from 0-10mg/L. The lowest value of TSS observed in February was 0mg/L (TSS not detected) in the tap water of S2, S5 and S6. The highest value of TSS observed in February was 10mg/L in the tap water of S3 and S4.

The tap water TSS for all the six locations varies from month to month. The permissible limits prescribed by WHO for TSS in drinking water is 5mg/L respectively. In November TSS in tap water of S2 (10mg/L), in December TSS in tap water of S1 and S6 (11mg/L and 5.5mg/L), in January TSS in tap water of S1 and S6 (20mg/L) and in February TSS in the tap water of S3 and S4 were found to exceed the limit set by WHO, as shown in Figure 11 respectively. The possible reason for such increase in the concentration of TSS could be the leakage in distribution system and corrosion of metallic pipes. According to a related study conducted by Amin et al.[17] TSS of water samples from 10 different water distribution systems in Peshawar were found in the range of 2-11mg/L. Where the TSS in some locations was found above the recommended limit set by WHO thus supporting the present study. Water containing high levels of TSS more than 5mg/L is not recommended for drinking purposes as that water is contaminated and can cause numerous waterborne diseases.

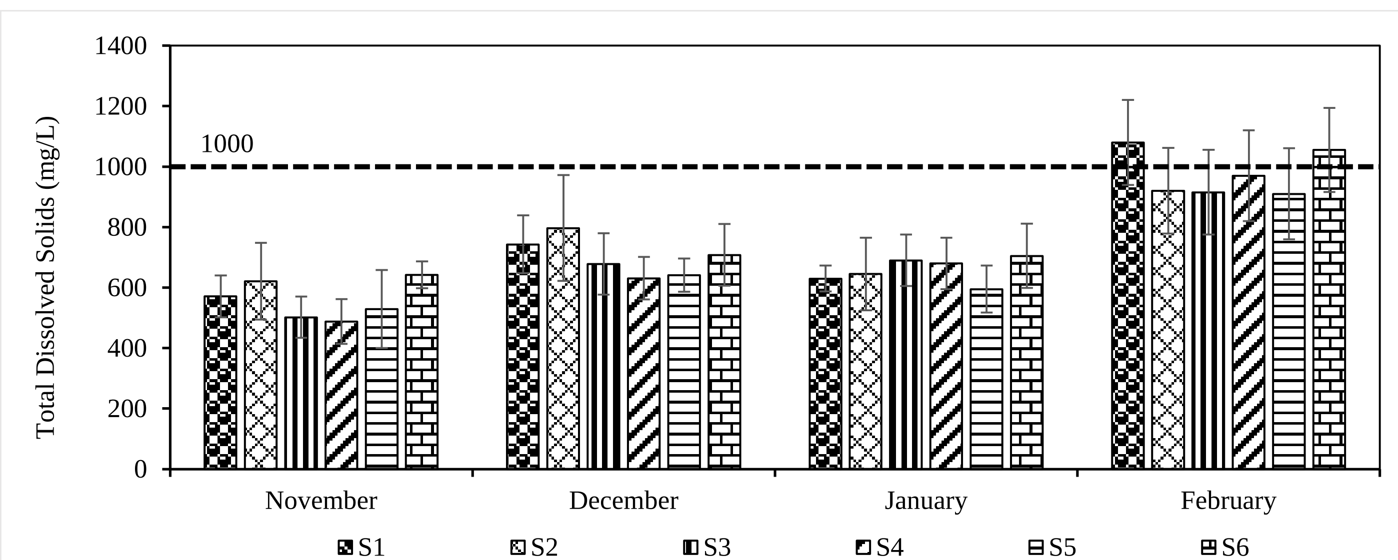

Figure-10: Temporal variation in TDS profiles of tap water from selected sampling stations. Dash line indicates the WHO standard[21] and PSDWQ[22].

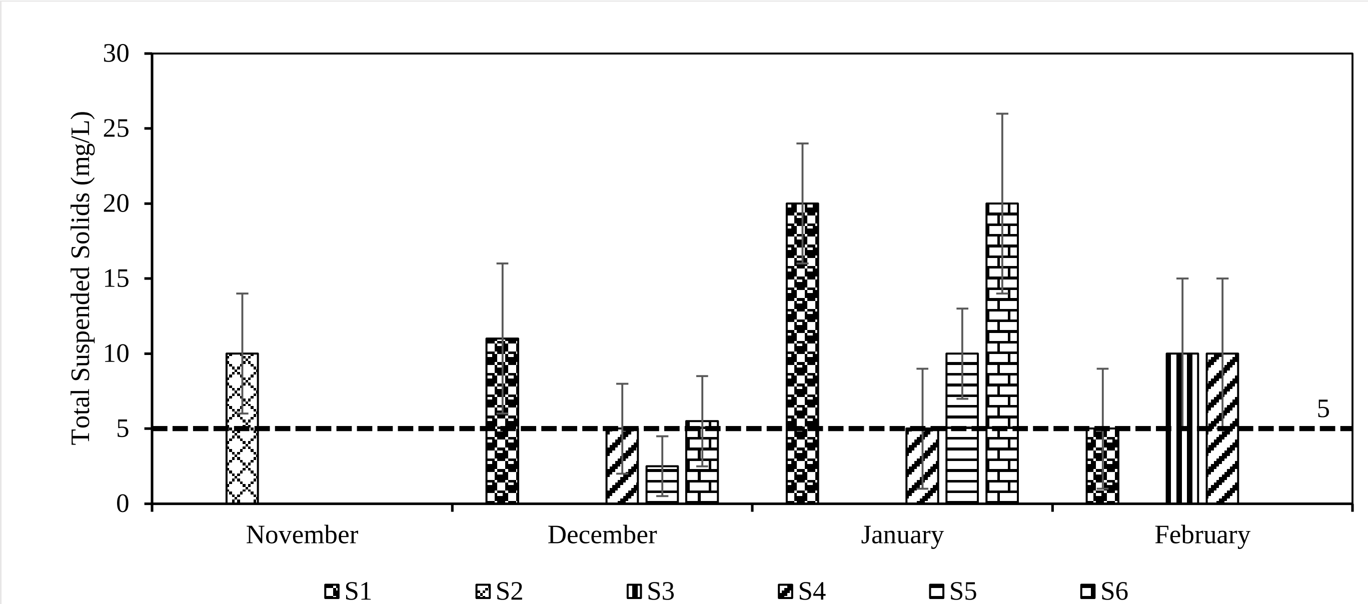

Figure-11: Temporal variation in TSS profiles of tap water from selected sampling stations. Dash line indicates the WHO standard[21].

Bacteriological Analysis: Total and Fecal Coliform: The existence of coliform bacteria in drinking water is an indicator which demonstrates the presence of organisms that can lead to waterborne diseases[1]. *Escherichia coli* is considered as the most susceptible indicator of fecal pollution[9]. In this study the value of total and fecal coliform in tap water in the month of November among the six locations were found in the range of 12 to >23MPN/100ml respectively. The lowest value of total and fecal coliforms observed in November was 12 MPN/100ml (95% probability range 4.8-24) in the tap water of S2, whereas the highest value of total and fecal coliform observed in November was >23MPN/100ml (95% probability range 13-…..) in the tap water of S4. In December the value of total and fecal coliform in tap water among six locations were found in the range of 5.1 to >23MPN/100ml respectively. The lowest value of total and fecal coliforms observed in December was 5.1MPN/100ml (95% probability range 1.6-13) in the tap water of S2, whereas the highest value of total and fecal coliforms observed in December was >23MPN/100ml (95% probability range 13-…..) in the tap water of S3, S4 and S5. The value of total and fecal coliforms in tap water in the month of January among the six locations ranged from 16 to >23MPN/100ml respectively. The lowest value of total and fecal coliform observed in January was 16MPN/100ml (95% probability range 5.8-34) in the tap water of S5 and S6, whereas the highest value of total and fecal coliform observed in January was >23MPN/100ml (95% probability range 13-….) in the tap water of S1, S2 and S3. In February the value of total and fecal coliform in tap water among the six locations ranged from 12 to >23MPN/100ml, where the lowest value of total and fecal coliform observed in February was 12MPN/100ml (95% probability range 4.8-24) in the tap water of S2 and the highest value of total and fecal coliforms observed in February was >23MPN/100ml (95% probability range 13-…) in the tap water of S3 and S5.

The values of total and fecal coliform among the six locations vary from month to month. The permissible limit of total and fecal coliform in drinking water as set by WHO and PSDWQ is 0 MPN/100ml. However in this study the amount of total and fecal coliform in tap water of all the six locations in every selected month was found far exceeding the limit as shown in Table 3 respectively. By analyzing the results of Table-3 it was concluded that the tap water of S2 was less contaminated as compare to the tap water of rest of the locations, but still far contaminated than the recommended limit. According to a related study conducted by Amin et al.[17] in which bacteriological analysis of drinking water distribution network of 10 locations in Peshawar, Pakistan was assessed through MPN technique. MPN index was found in the range of 1.1- >23 MPN/100ml. Which supported the present study as it also exceeds the recommended limit by WHO and PSDWQ.

As the selected months for analysis cover the winter season than naturally the bacterial growth should be less, but still the present study highlights high levels of bacterial contamination. The main reason is lower and almost negligible amount of residual chlorine detected at consumer end. The main problem lies in the amount of chlorine which should be added to maintain residual chlorine till the consumer end, which was confirmed from the previous initial study on the raw and chlorinated water which concluded that far less amount of chlorine required for chlorination was being used. Leakage in pipes, old drinking water distribution systems and formation and detachment of biofilms along the inner surface of pipes may cause the contamination of potable water.

Table-3: Temporal variation in MPN Index of tap water from selected sampling stations.

Months	MPN Index/ 100ml	Sampling Stations						WHO & PSDWQ Limits
		S1	S2	S3	S4	S5	S6	
November	MPN Index	16	12	16	>23	16	16	0/100ml
	95% Probability range	5.8-34	4.8-24	5.8-34	13-….	5.8-34	5.8-34	
December	MPN Index	23	5.1	>23	>23	>23	23	
	95% Probability range	8.1-53	1.6-13	13-….	13-….	13-….	8.1-53	
January	MPN Index	>23	>23	>23	23	16	16	
	95% Probability range	13-….	13-….	13-….	8.1-53	5.8-34	5.8-34	
February	MPN Index	23	12	>23	16	>23	16	
	95% Probability range	8.1-53	4.8-24	13-….	5.8-34	13-….	5.8-34	

Recommendations: i. The drinking water distribution system should be regularly monitored and maintained for the improvement of water quality. ii. Leaking and old pipes should be replaced with new ones to prevent bacterial contamination. iii. Proper dosage of chlorine at the source should be exercised to maintain levels of residual chlorine at the consumer tap for maximum disinfection. Operators should be trained to administer proper dose of chlorine. iv. Residents should be advised to boil the water before consuming it. v. For efficient removal of coliforms it is recommended that Reverse osmosis and UV disinfection should be used.

Conclusion

Access to safe and clean drinking water is necessary for good health. Drinking contaminated water may result in severe waterborne diseases, some of which are even fatal. The study concludes that physicochemical parameters of tap water during the studied months were found within the prescribed limits set by WHO and PSDWQ, except few parameters such as DO, TDS, TSS, Free & total chlorine. DO, TDS and TSS were found above the recommended limits in the tap water, whereas free and total chlorine was found far below the recommended value, almost negligible at consumer end thereby making tap water not suitable for consumption. Microbial analysis of tap water revealed that it was highly contaminated. Elevated levels of microbes may be linked with low levels of chlorine detected. Regular monitoring of water and proper dosages of chlorine are required to prevent microbial contamination. As the study highlights the flaws in the existing system, if addressed it will help in improving the quality of water to the users.

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