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Microbiological quality of drinking water in urban communities, Rawalpindi, Pakistan

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ABSTRACT

Bacterial contamination and residual chlorine were investigated over a three month period in four different areas of Rawalpindi city namely Ratta Amral (R1), Satellite town (R2), Westridge (R3), and Tench Road (R4). Treated water from Khanpur and Rawal Lake Filtration Plant is supplied to these communities, which treat surface water with conventional processes (coagulation, flocculation, and sedimentation). Eight sampling sites were chosen from each area to give wide geographic coverage and correspondingly, wide range of water residence times. The drinking water quality in the distribution network was evaluated by measurements on water samples taken from the water source, overhead reservoir and residential taps. Parameters include temperature, pH, turbidity, total dissolved solids (TDS), conductivity, total organic carbon (TOC), disinfectant residuals, coliforms, and Spread plate count (SPC) as per standard methods. Significant losses were observed in both chlorine and chloramine residuals in R1 and R4 areas that may result in bacterial regrowth. Coliform bacteria were detected in all areas except at sampling sites of R2. TOC varied from 0.39 to 5.97 mg/L. Chlorine residual at consumer end ranged from below detectable limit (BDL) to 0.36 mg/L. TDS varied from 141.1 to 512 mg/L and conductivity ranged between 286.3 and 1023 μS/cm, while turbidity fluctuated between 0.16 and 4.10 NTU. Evaluation of the treated water quality indicates that the water is not suitable for drinking and requires improvement in conventional treatment followed by implementation of monitoring and surveillance of the distribution network. The finished water quality fails to meet the level of standards as described by WHO for potability mainly in terms of its microbial characteristics.

Keywords: Disinfectant residual; Coliforms; TOC; Drinking water; Distribution network

1. Introduction

Rawalpindi is the third largest city of Pakistan. It is located near the capital city of Islamabad, in the province of Punjab. Water supply in Rawalpindi is under the responsibility of Water and Sanitation Agency (WASA). WASA is mandated to provide a sufficient quantity of drinking water to the community. WASA (Rawalpindi) was created with the aim of supplying water, providing sewerage treatment services and maintaining drainage facilities to the residents of the city.

There are two main sources of drinking water in Rawalpindi, groundwater and surface water. Groundwater is obtained with the help of 270 tube wells, supplying approximately 26 million gallons of water

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per day (MGD) to the residents of Rawalpindi. Surface water is supplied from Khanpur Dam through Sangjiani Water Treatment Plant out of the total production and Rawal Lake through a 23-MGD Rawal Lake Filtration Plant.

Drinking water supplied by densely populated municipalities (Karachi, Lahore, Rawalpindi, Peshawar, Faisalabad, Qasur, Sialkot, and Gujarat) to the public in Pakistan is mostly contaminated with infectious microorganisms or hazardous chemicals and cannot be recommended for human consumption [1,2]. The situation is even worse in the capital city Islamabad. Analysis of water samples from Islamabad and its twin city Rawalpindi revealed that 94 and 34% of water samples, respectively, contained total coliforms and fecal coliforms [3]. Pakistan Council of Research in Water Resources (PCRWR) conducted a detailed study on water quality in 23 major cities in all the four provinces of the country from 2002 to 2006. The conclusion of this study reveals that an average of 84–89% of water sources throughout the country have water quality below the recommended standards for human consumption [4].

Generally, water pressure in the distribution network is low, with leaky pipes, which leads to infiltration of contaminated water. Major outbreaks of waterborne epidemics swept the cities of Faisalabad, Karachi, Lahore, and Peshawar in 2006, as a result of sewage and industrial waste leaking into drinking water through damaged pipes [5]. Estimates indicate that each year, more than three million Pakistanis become infected with waterborne diseases [6]. Major diseases linked to drinking water are diarrhea, gastroenteritis, typhoid, cryptosporidiosis, giardiasis, intestinal worms, and hepatitis. In several areas, increased arsenic, nitrate, and fluoride contamination in drinking water was also detected [7].

The water sector in Pakistan faces major challenges such as poor quality of service, intermittent water supply in urban areas, inefficient water disinfection practices and lack of water quality monitoring at treatment plants. In addition, many service providers do not even cover the costs of operation and maintenance due to low tariffs and poor efficiency [5]. Consequently, the service providers strongly depend on government subsidies and external funding [8].

The parameters recommended by World Health Organization (WHO) for the minimum monitoring of community supplies namely, (a) *Escherichia coli* and thermo-/tolerant coliforms accepted as suitable substitutes, (b) chlorine residual (if chlorination is practiced), (c) pH, and (d) turbidity ensure the hygienic state of water and reduce the risk from waterborne pathogens [9]. Coliforms principally occur in water used for domestic, industrial or other purposes [10]. High levels of coliform counts indicate a contaminated source, inadequate treatment or post-treatment deficiencies. Few data on the bacterial quality of water supply in rural areas exist, since most studies are conducted in urban communities [11].

Hence, the main objective of the present study was to determine the level of contamination in drinking water supplied to the community and to emphasize the importance of regular monitoring of water distribution networks for continuous supply of clean water. It was hoped that information from this study might help to facilitate source water protection and establish more effective water treatment strategies and improved system surveillance.

2. Materials and methods

2.1. Water sampling

During a four month study (November 2007–February 2008), standard methods were followed in collecting, handling and analyzing the 96 samples (eight samples from each zone in triplicate) from water supply lines of different areas: Ratta Amral (R1), Satellite Town (R2), Westridge (R3), and Tench Road (R4) of Rawalpindi city. These sites were selected on the basis of diarrheal and other gastrointestinal cases documented at local government hospitals or reported in daily newspapers. Water regulating authorities were also consulted in this regard to select representative sampling sites. Total dissolved solids (TDS), pH, and electrical conductivity were analyzed onsite. Water samples were stored in ice boxes and transported to the laboratory for physico-chemical (turbidity, total organic carbon [TOC], total and free chlorine) and microbiological (total coliform and fecal coliform) analysis within 2 h.

2.2. Microbiological analysis

Coliform and fecal coliform tests were performed according to standard methods by collecting water samples in sterile glass bottles containing 3–4 drops of 3% sodium thiosulphate in order to neutralize any residual chlorine. The total coliform and fecal coliform count was determined by multiple tube dilution using lactose broth for the presumptive test followed by confirmation with brilliant green lactose broth + 2% bile. Heterotrophic plate counts (HPC) were also determined as per standard methods (9215 C) [12] by inoculating 0.5 and 1.0 mL for each sample into molten nutrient agar before plating. The plates were incubated at 37°C for 24–48 h, and CFU/ml was determined [13].

2.3. Physicochemical analysis

Chlorine residual, free and total chlorine, monochloramine, and dichloramines were determined by N,N Diethyl-1,4 Phenylenediamine Sulfate (DPD) ferrous titrimetric method [12] using a ferrous ammonium sulfate (FAS) titrator. For the detection of free chlorine, 5 mL of phosphate buffer and DPD were placed in a flask with 100 mL sample; development of red color was titrated against standard ferrous ammonium sulfate. All chlorine concentrations were reported as milligrams available chlorine per liter.

Turbidity was determined using a nephelometric method using a Hach model 2100A turbidity meter. Similarly, temperature and pH were measured using a Hach pH meter sension 1, whereas TDS and electrical conductivity were measured using a Hach meter (sension 5). TOC was analyzed with a TOC analyzer multi win N/C 30.

3. Results and discussion

The purpose of this study was to monitor the water distribution network of Rawalpindi area for pathogenic microorganisms in water sources used by urban communities. Such information may allow us to determine to what extent the supply water is being disinfected and also to monitor any contamination in the distribution system. Both ineffective treatment and contamination in the distribution system expose the community to infectious diseases. The water was sampled in a winter season with heavy rainfall. This climatic environment can further deteriorate water quality in the distribution network due to stagnant pools and a high rate of infiltration. The summers in the study area usually have low rainfall. Drinking water quality was evaluated on the basis of WHO standards.

3.1. Physical quality

The physical quality of drinking water at the filtration plant was satisfactory with temperature ranging from 16.4 to 19.5°C, TDS varying from 193.7 to 198.4 mg/L, electrical conductivity between 388 and 397 μS/cm, and turbidity between 0.31 and 0.66 NTU. The mean temperature for samples collected from different areas of Rawalpindi district ranged from 12.8 to 19.9°C (Fig. 1A). Most of the samples had temperatures above WHO limit of 12°C. Temperature is a critical water quality and environmental parameter because it governs the kinds and types of microbial growth, regulates the maximum dissolved oxygen concentration of the water, and influences the rate of chemical and biological reactions in the water. In a previous study conducted by Farooq et al. [14] in which the samples were collected from different areas of Rawalpindi in the summer, temperatures fluctuated from 26.5 to 27.6°C. This high temperature resulted in microbial contamination at specific sampling points.

Out of 96 collected samples, 15 samples from R1 had TDS above the highest desirable limit (HDL) of 500 mg/L (Fig. 1B). TDS concentrations from all the other areas were below the HDL. Reliable data on possible health effects associated with the ingestion of TDS in drinking water are not available, but water containing less than 1, 000 mg TDS/liter is usually acceptable to consumers. High TDS levels in water may be objectionable to consumers owing to the resulting taste and to excessive scaling in water pipes, heaters, boilers, and household appliances. Water with extremely low concentrations of TDS may also be unacceptable because of its flat, insipid taste and is also often corrosive to water supply systems [15].

The electrical conductivity at the sampling sites ranged from 401 to 818 μS/cm at R3 and R1, respectively. All of the samples were above the maximum permissible limit (MPL) of 400 μS/cm and therefore high in soluble salt [16].

Turbidity in R1 varied from 2.82 to 4.1, nephelometric turbidity unit (NTU), above the HDL of 2.5 but was below the MPL of 5.0 NTU. This high turbidity might be due to the fact that groundwater from the tube wells is being mixed into the water supply of the distribution network, to increase the pressure in the pipelines before supplying it to the residents of area R1. For the rest of the sampling areas, turbidity was low (Fig. 2). Excessive turbidity, or cloudiness, in drinking water is esthetically unappealing, and may also represent a health concern. Although turbidity is not a direct indicator of health risk, numerous studies show a strong relationship between removal of turbidity and removal of protozoa [17].

The particles which contribute to turbidity provide nutrients and "shelter" for microbes reducing their exposure to attack by disinfectants. Microbial attachment to particulate material or inert substances in water systems has been documented by several investigators [18–19] and can aid in the survival of microbes [20]. Fortunately, traditional water treatment processes have the ability to effectively remove turbidity when operated properly. In Pakistan, conventional methods of sedimentation and filtration are used for turbidity removal. Alternatively advanced methods like reverse osmosis or membrane filters achieve the desired water quality.

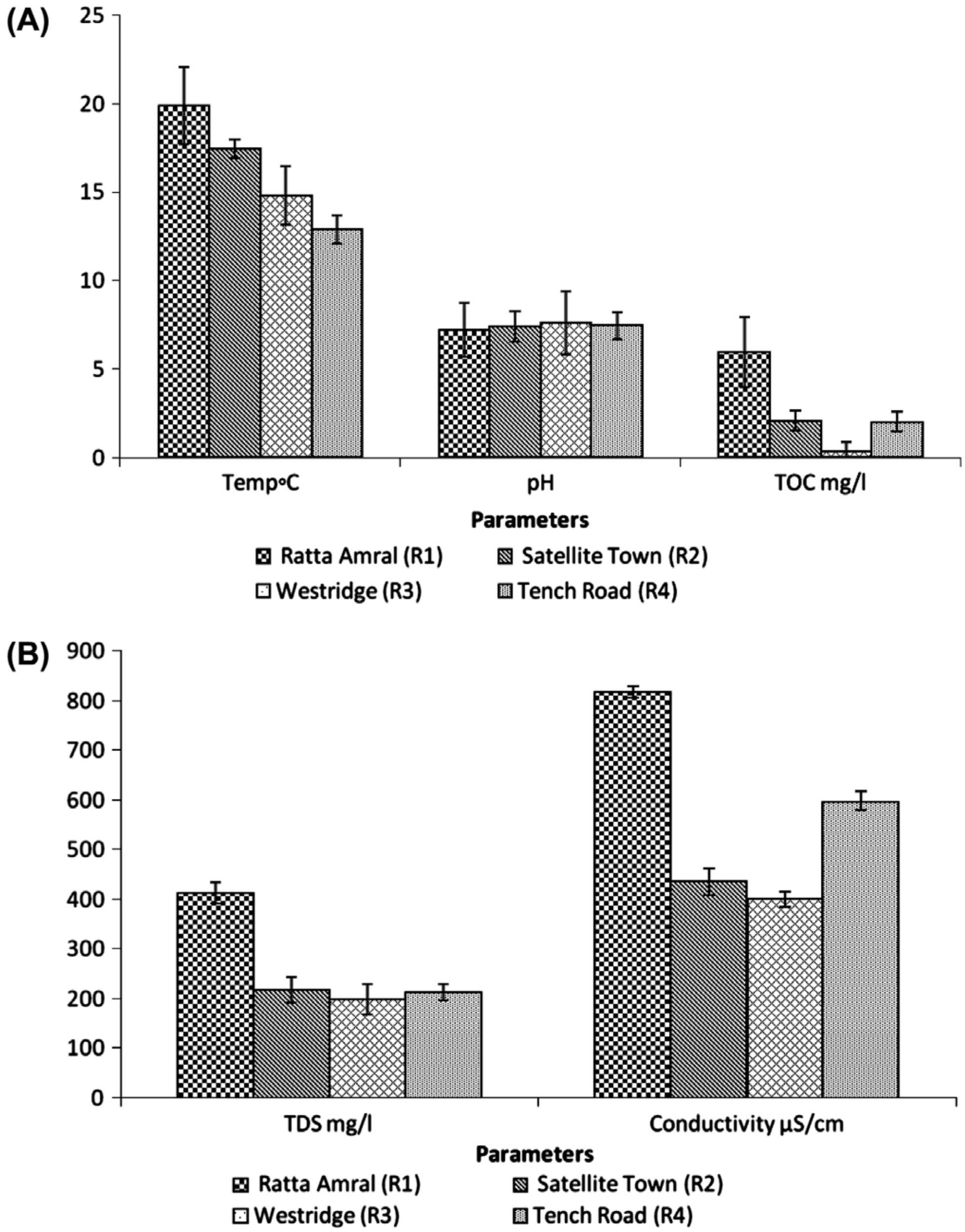

Fig. 1. Physiochemical parameters of various sampling sites.

3.2. Chemical quality

The mean pH ranged from 7.2 to 7.6 and none was above HDL of 8.5 (Fig. 1A). These results are in agreement with Farooq et al. [14] who reported pH values of 6.5–8.5 within WHO permissible limit. Although pH usually has no direct impact on water consumers, it is one of the most important operational water quality parameters. Careful attention to pH control is necessary at all stages of water treatment to ensure satisfactory water clarification and disinfection. The pH of the water entering the distribution system must be controlled to minimize the corrosion of water mains and interior plumbing systems. Failure to control pH can result in the contamination of drinking water and adversely affect taste, odor, and appearance [21].

TOC was highest at R1 sampling points which had a mean value of 5.97 mg/L (Fig. 1A). In R4 TOC varied from 0.4 to 4.28 with an average of 2.02 mg/L, and in R2 it ranged from 0.92 to 3.61 mg/L (mean value 2.02 mg/L). The lowest TOC was detected at the R3 sampling sites with values ranging between 0.06 and

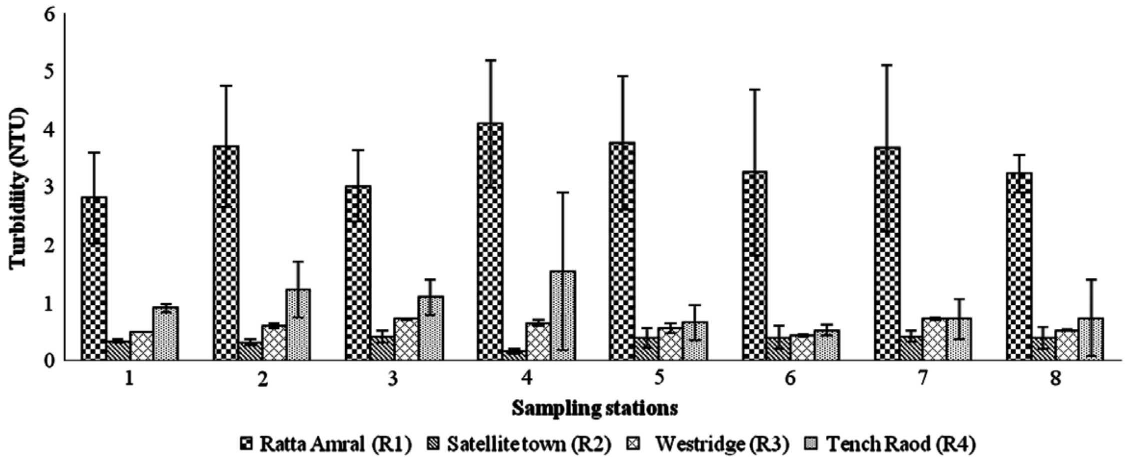

Fig. 2. Turbidity values at selected sampling points.

1.1 mg/L. The high TOC might be due to decaying natural organic matter and from synthetic sources such as detergents, pesticides, and fertilizers [22]. The permissible limit of TOC for treated water is 2 mg/L. Before source water is treated for disinfection, TOC analysis quantifies the amount of natural organic matter (NOM) in the water source. Many researchers have determined that higher levels of NOM in source water during the disinfection process will increase the amount of carcinogens in the processed drinking water. Epidemiological studies have indicated a slightly increased risk for bladder, colon, and rectal cancers in individuals who were exposed to chlorinated surface waters for many years [23]. In addition, some epidemiological studies have shown an association between the consumption of chlorinated drinking water and adverse reproductive or developmental health effects, such as spontaneous abortion or fetal anomalies [24].

Residual chlorine concentration in drinking water samples collected from R1 sampling sites was below detection (Fig. 3). Depleted residual chlorine resulted in severe microbial contamination as indicated in Fig. 4. These results are in agreement with the study carried out by Farooq et al. [14], who found an inverse relation between microbial density and chlorine residual. Based upon these properties, drinking water chlorination will remain a cornerstone of preventing waterborne diseases. Similarly in R4, residual chlorine decreased from 0.52 mg/L at the filtration plant to 0.12 mg/L at the consumer end. The WHO recommended dosage of chlorine at the point of usage is 0.2–0.5 mg/L [25]. In R3, disinfectant residual ranged from 0.23 to 0.42 mg/L, while in R2 it ranged from 0.03 to 0.13 mg/L (Fig. 3).

Chlorination for drinking water disinfection is effected by many factors including pH, temperature, amount of chlorine added, and contact time. Variations in temperature, pH, chlorine demand, time, and types of organisms in the water affect the efficacy of the applied dose. Chlorine effectively inactivates the majority of *E. coli* common indicators of fecal contamination. *E. coli* at a concentration of 0.2 mg/L Cl_2 for 3 min reduces by 99.99% [26].The effect of pH varies with the nature of the disinfectant and is most pronounced for chlorine. According to a Defense Technical Information Centre (DTIC) report, disinfection efficiency for all the enteroviruses exhibited anomalous two-stage disinfection kinetics at pH 5, making disinfection of these viruses fast or faster at pH 7 than at pH 5 [27]. According to WHO Guidelines, disinfection should be carried out at pH less than 8 and at a free chlorine concentration $\geqslant$ 0.5 mg/L [25].

Jarrol et al. [28], tested the viability of *Giardia lamblia* cysts against chlorine dosage and found that at 25° C, exposure to 1.5 mg of chlorine per liter for 10 min at pH 6, 7, and 8 inactivated all cysts. At 15°C, 2.5 mg of chlorine per liter for 10 min killed all cysts at pH 6. With this higher chlorine concentration and pH 7–8, a small number of cysts remained viable after 30 min but were ultimately disinfected after 60 min. In another study by Kenyon and Katheryn [29], a comparative evaluation of the kinetic inactivation by free available chlorine (FAC) of different bacterial species including *E. coli*, *Salmonella typhimurim*, *Shigella boydii*, and *Vibrio cholerae* revealed that disinfection efficacy was reduced during low temperature and high pH test conditions.

3.3. Bacteriological quality

At the filtration plant, no microbial contamination was detected throughout the sampling period; however, indication of microbial contaminants at the

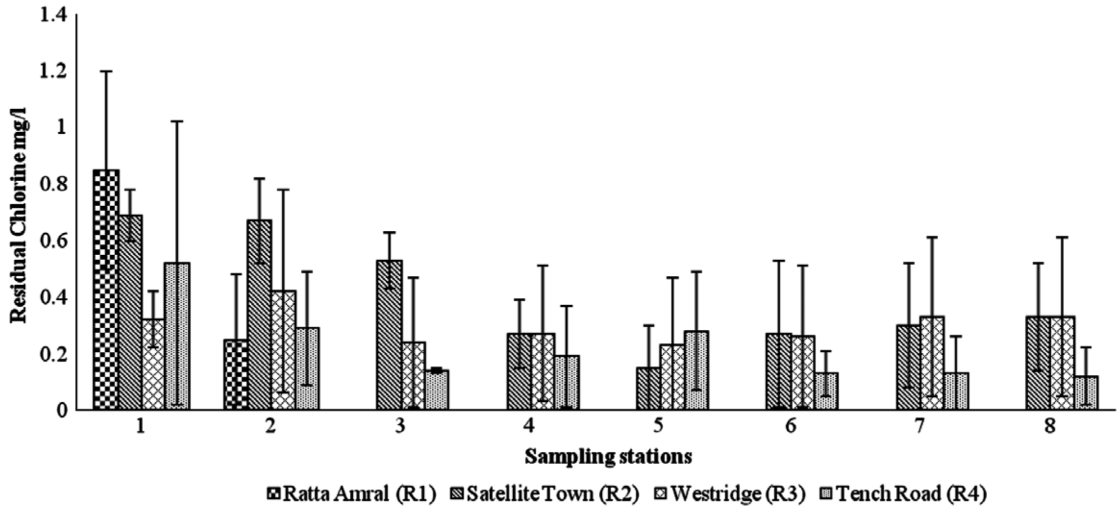

Fig. 3. Residual chlorine concentration at selected sampling points.

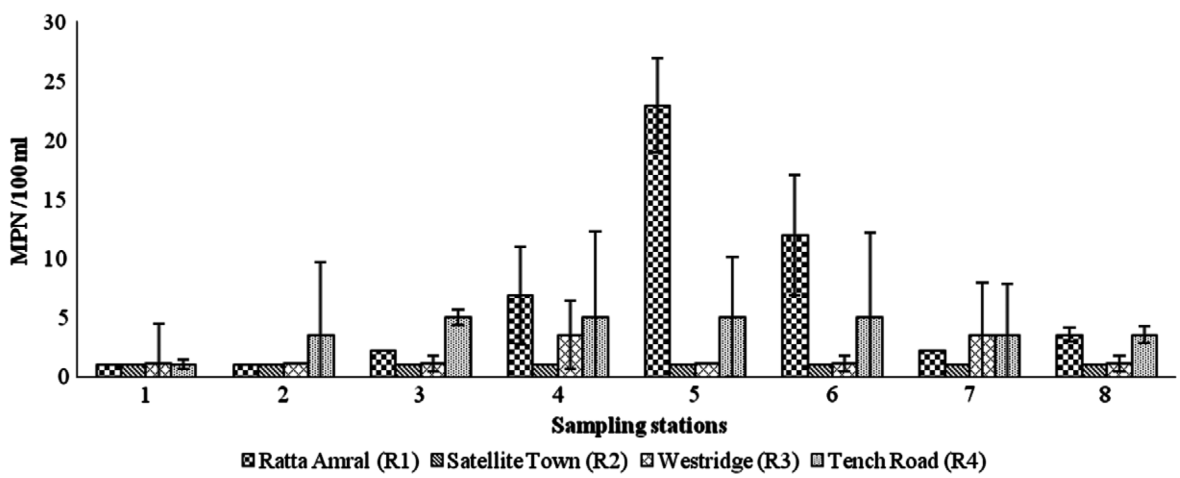

Fig. 4. Fecal coliform counts obtained at selected sampling points.

consumer end showed water quality deterioration as it flowed through the distribution network. Total coliforms ranged from 0 to 23.0 MPN/100 mL. Out of 96 samples, 37.5% were positive for coliform. Further analysis showed that a majority of the positive samples were from R1 and R4 area. A few sites in R3 were also positive for fecal coliform (Fig. 4). The samples collected from R2 were free of fecal coliform. The presence of coliform in water was mainly due to unhygienic condition prevailing in R1 and R4 area. These are undeveloped areas with congested streets, open drains, and inefficient water supply system. Many of the water supply pipes were leaking and placed in proximity to sewer lines or passing through open sewers, resulting in cross contamination. Reduced water pressure in supply lines usually causes infiltration of sewage. Most of the residents in these two areas reported suffering from gastroenteritis, diarrhea, and hepatitis A and hepatitis E (problems communicated from the local resident medical officer). It is practically impossible to accurately manage the distribution of disinfectant residual using only traditional water quality control options, which adjust the chlorine residual at points of entry into the distribution system (i.e. at treatment plant, clear wells, or ground water wells). Water utilities must balance between excessive disinfectant concentrations near the source and loss of efficacy against pathogens control at the network periphery. Booster chlorination (the addition of chlorine at distinct locations throughout the distribution system) may produce a more uniform disinfectant residual and will be more effective in combating the infiltration of microbial pathogens [30].

These results are in line withthose of Shar et al. [16] who collected drinking water samples from different points of Khairpur city, i.e. main reservoir ($n = 24$), distribution line ($n = 24$), and consumer taps ($n = 24$). Out of 72 samples tested, 80.6% were positive for thermotolerant *E. coli*. Shar et al. [16] concluded that water used for drinking purpose in Khairpur city was an important source of waterborne disease like diarrhea, gastroenteritis, and dysentery. Drinking water of many localities in Karachi was also found contaminated with high numbers of fecal coliform [31]. Collectively, our work and that of those researchers have shown that the quality of drinking water in most cities of Pakistan is not good [14,16,31].

E. coli; a fecal coliform is a commensal bacterium of the intestinal tract of humans and various animal species. Although more *E. coli* strains are harmless, a few are causative agent of diarrhea. Among the many harmless strains, pathogenic isolates exist; and such strains can be harmful, especially for children but even for fully immunocompetent adults as well as animals [32]. There have been reports of coliform outbreaks: sudden increase in coliform numbers in drinking water distribution systems in various parts of the world [33–36]. In some instances, it has been possible to rule out cross contamination or inadequate treatment as the cause of these outbreaks. This has led to the conclusion that the bacteria involved in these outbreaks originate within the water distribution system itself. In such a case, the growth of bacteria on pipe walls (biofilms) and their subsequent sloughing off would also enable these outbreaks.

The culturable count in water samples was determined by HPC technique. It is a procedure for estimating the number of live heterotrophic bacteria (requiring organic compounds of carbon and nitrogen for nourishment) in water. This test can provide useful information about water quality and supporting data on the significance of coliform test results. High concentrations of the bacterial heterotroph population may hinder the recovery of coliforms. HPC ranged from 1 to 133 CFU/mL among all the collected water samples (Fig. 5). Lower HPCs were detected at R3 and R2. The highest HPCs were detected at R1, whereas in the R4 area, maximum counts of 108 CFU/mL were detected. These results are in agreement with the findings of Farooq et al. [14] and Hashmi et al. [37]. Hence enumeration of HPC is a useful indicator of opportunistic pathogens, a potential hazard for coliform suppression and drinking water quality deterioration in distribution systems [38]. Unlike other indicators, such as *E. coli* or total coliforms, low concentrations of heterotrophic bacteria will still be present after drinking water treatment. In general, water utilities can achieve heterotrophic bacteria concentrations of 10 colony-forming units (cfu/mL) or less in finished water. Within a distribution system, increases in the density of HPC bacteria are usually the result of bacterial regrowth. The density reached can be influenced by the density of bacteria in the finished water, temperature, residence time, presence or absence of a disinfectant residual, construction materials, surface-to-volume ratios, flow conditions, availability of nutrients for growth and in chlorinated systems, the chlorine/ammonia ratio, and the activity of nitrifying bacteria.

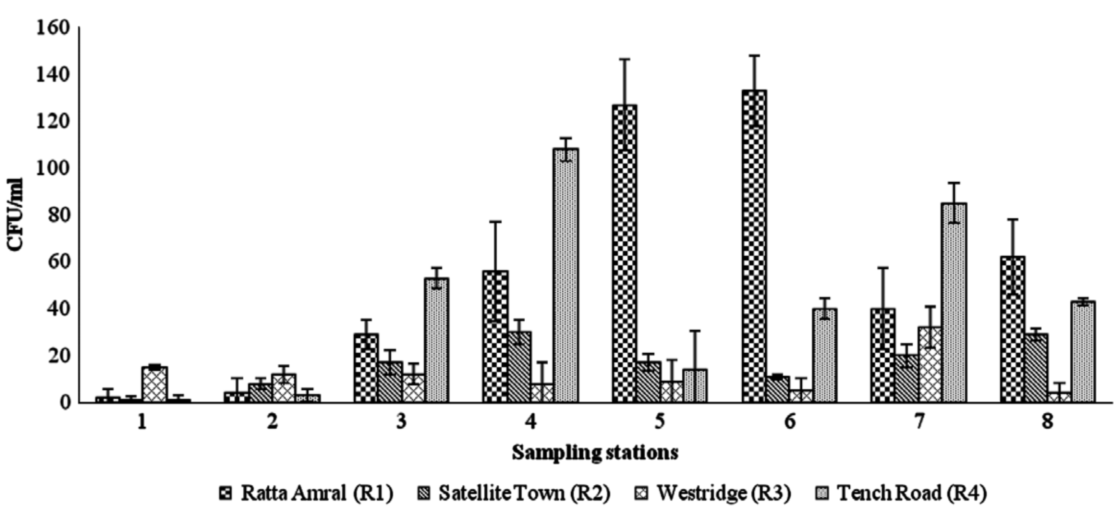

Fig. 5. SPC values obtained at selected sampling points.

4. Conclusion

Results showed that all the four sampling areas of Rawalpindi city had pH within the WHO limit but exceed recommended temperature ranges. The water samples from one of the four localities (R1) had high TDS, turbidity, and TOC. R1 did not have any detectable residual chlorine concentration. High electrical conductivity values were obtained at all the water sampling sites. Fecal contamination was high in R1 area possibly because of regrowth or intrusion of microorganisms in the absence of chlorine residual. Incidences of fecal coliform contamination were also detected at R3 and R4. The common diseases like gastroenteritis, diarrhea and hepatitis A and hepatitis E that prevailed in these areas may be due to the poor quality of water being supplied. Hence to meet the goal of clean, safe drinking water with no fecal coliforms and *E. coli*/100 mL of drinking water sample, a multi-barrier approach that includes: protecting source water from contamination, appropriately treating raw water, ensuring safe distribution of treated water to consumer's taps, routine monitoring of water quality parameters in the distribution network, and vigilance of water regulating authorities is required. Shortage of qualified manpower and funds in the study area, has led to the inadequate provision of water and sanitation services. The gap is further enlarged by the lack of unambiguous definition of responsibilities, work plans and targets; ineffective coordination and a lack of communication between federal, provincial, and local administrative entities.

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