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Bacteriological and Physicochemical Quality Assessment of Drinking Water from Water Storage Tanks of National University of Sciences and Technology (NUST), During Pre-Monsoon and Monsoon Seasons

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Abstract. Water is essential for life, but it is being polluted at a significant rate. The current study aimed to assess the drinking water quality in storage tanks at the National University of Sciences and Technology in Islamabad, Pakistan over six months, including pre-monsoon and monsoon seasons. Various physico-chemical parameters were tested including residual chlorine, total dissolved solids (TDS), total suspended solids (TSS), dissolved oxygen (DO), pH, turbidity, alkalinity, hardness and electrical conductivity (EC). All parameters were found to be within permissible limits of world health organization (WHO) and Pakistan standards for drinking water quality (PSDWQ) except DO, TSS and residual chlorine in both seasons. However, the alarming situation is the presence of high microbial contamination revealed by using the most probable number (MPN) technique, with MPN values ranging from 16 to >23 for raw water in underground tanks and 2.2 to >23 for chlorinated water in overhead tanks, attributed to low residual chlorine detection in both seasons. Pearson's correlation matrix and PCA highlighted strong correlations among parameters and key factors influencing water quality. The paired *t*-test indicated that there was no statistically significant difference in water quality between underground and overhead storage tanks during both seasons. The findings revealed that the water is unfit for drinking, requiring improved chlorination and control measures.

Keywords: raw water, chlorinated water, storage tanks, microbial and physico-chemical parameters, national university

Introduction

Water scarcity is a topographic predicament in limelight which has potential to spiral out of control and endanger a global water crisis soon (Khalid *et al*., 2018). The categorization and documentation of water as potable requires meeting certain chemical, physical and microbial standards specifically designed to confirm its potability and safety for drinking purposes (Fikre, 2020).

Drinking water pollution has been a worldwide challenge posing grave repercussions for human health. Approximately 28% of the global population falls short of access to adequate water (Ondieki *et al*., 2021). Water-borne diseases, inadequate sanitation and poor hygiene are reported to cause around 6000 children-related fatalities WHO/UNICEF (2014, 2021). Indiscriminate access to the sustainably managed water and sanitation systems by 2030 is envisioned by Sustainable Development Goal 6 (SDG 6). Water quality monitoring is imperative to ensure the provision of potable water and enhancing water management (Murei *et al*., 2024). In order to make informed decisions regarding protection and management of water reservoirs, water quality characterization data is collected to determine the extent of contamination in them (Din *et al*., 2023).

Lack of access to microbiologically safe drinking water and insufficient sanitation capacity has jeopardized the wellbeing of 10 Million people causing diseases such as diarrhea, salmonellosis, skin problems, cholera, dysentery and certain types of gastrointestinal diseases, neurological and reproductive disorders leading to high rate of morbidity and mortality (Akhtar *et al*., 2019). A particularly significant risk is associated with fecal contamination, among others, owing to its association with multiple water-borne diseases. In order to understand the potential hazards and implement effective mitigation strategies, conducting a thorough risk assessment of fecal contamination in water resources is crucial (Murei *et al*., 2024). Many developing countries are particularly susceptible to dearth of water resources

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further exacerbated by unplanned population growth. According to studies more than 5 Million fatalities, mostly in developing nations, have been attributed to the intake of contaminated food and water (Ondieki *et al*., 2021) and degraded water quality is considered as one of the indicators of poverty in these countries. Consequently, overhauling of drinking water supply infrastructure, sanitation facilities and phasing-out of water-borne maladies are one of the major components of UN sustainable development goal (SDG) programs and are covered under goal 6 (Duressa *et al*., 2019). WHO recommends pathogen-free potable water to remain out of the reach of many preventable ailments.

Being a developing country, Pakistan has been plunged into direct plight of water quality. Approximately, 30% of all diseases and 40% of all fatalities in Pakistan are attributed to poor water quality. Furthermore, every year over 3 Million people in Pakistan are forced to endure water-borne diseases and out of these affectees, 0.1 Million succumb to death (Haydar *et al*., 2009). Diseases related to water, sanitation and hygiene (WASH) across Pakistan are estimated to deprive 110 children of right to live every day. The lack of legislative framework, poverty, lack of management and well-equipped laboratories for testing and monitoring drinking water quality further worsened the dilemma. Water pollution may occur at the source level, distribution lines, or at the household level and polluted water may prove to be a potent carrier of several pathogenic organisms (Sitotaw *et al*., 2021).

A healthy and safe environment of an educational institute incorporates the physical surroundings, the psychological, learning and health-promoting environment of the institution, which focuses on ailment prevention and ensures well-being for both students and staff (Bakir *et al*., 2015). The water quality of university is under consideration because students can be exposed to dangerous microbes from contaminated drinking water sources, which may cause water-borne epidemics (Hu *et al*., 2021). Water quality degradation between sources and points of use may be caused by a variety of factors, including the environment of storage and the sanitary state of water storage containers (Douhri *et al*., 2015). National University of Sciences and Technology (NUST) Islamabad, Pakistan is selected for this study as the university covers the area of about 707 acres with approximately 20,000 population including 4719 hostilities and 733 faculty members. Hostilities can suffer from multiple ailments and their overall efficiency towards academic activities may be compromised due to an increase in the rate of absenteeism. Moreover, study has found the strong correlation between reduced student absenteeism and the provision of free, safe drinking water at their educational institution (Hu *et al*., 2021). Drinking water at NUST is stored in tanks before distribution, creating conditions that may encourage microbial proliferation. These storage tanks play a critical role in maintaining water quality, directly influencing the safety and usability of stored water. Over time, they can accumulate contaminants, biofilms and sediments, potentially leading to microbial growth and chemical deterioration. Regular analysis of storage tanks is essential for ensuring compliance with water quality standards and safeguarding the health of students and staff. Despite the importance of this issue, limited research has been conducted on the microbial and physicochemical quality of drinking water storage tanks at NUST, particularly during the monsoon and pre-monsoon seasons. This gap in research needs to be addressed to enhance water quality management and mitigate health risks associated with contaminated storage tanks.

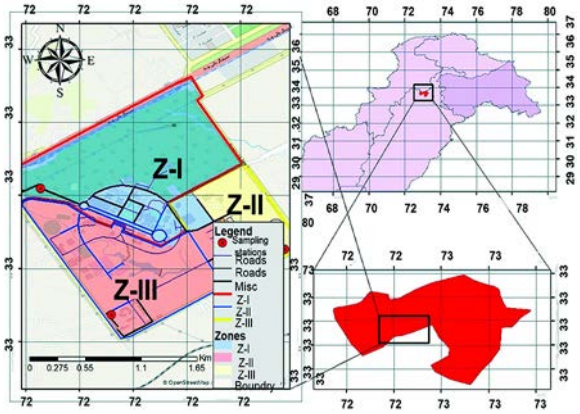
This study aims to assess the microbial and physicochemical quality of drinking water storage tanks at NUST during both the monsoon and pre-monsoon seasons to evaluate their role in potential contamination. By identifying contamination sources and associated risks, the findings will inform improved water quality management strategies, ensuring safer drinking water for the university community.

Materials and Methods

Study area. The study area is located within the National University located in Islamabad, Pakistan. University's water distribution system is mainly based on ground water. The university has three zones (Z-I, Z-II and Z-III) and each is supplied with water through tube wells. However, pumping capacity of tube wells is 0.2 Million gallons per day (MGD). There were total 11 tube wells out of which 9 were working during the sampling period. Tube wells water is pumped into underground storage tanks of each zone. A chlorination process is then used to disinfect the water before it enters the overhead storage tanks of Z-I and Z-II. Z-III has no overhead water storage tank so water after chlorination is directed towards drinking water distribution system (DWDS). Figure 1 shows the location

of sampling points. The latitudes and longitudes of each sampling point were also identified (Table 1) using the Global Positioning System (GPS).

Drinking water samples were collected from 6 sampling stations. Raw water was collected from underground storage tanks of all three zones and chlorinated water samples were collected from overhead storage tanks (except Z-III) for analysis in two seasons (pre-monsoon and monsoon). Underground storage tank of Z-I is marked as (ST Z-I R), chlorinated water was collected from overhead storage tank of Z-I which is marked as (ST Z-I Cl), underground storage tank of Z-II is marked as (ST Z-II R). Similarly, chlorinated water was collected from overhead storage tank of Z-II which is marked as (ST Z-II Cl), underground tank of Z-III is marked as (ST Z-III R) and chlorinated water was collected from tap besides the underground water storage tank of Z-III which is labelled as (ST Z-III Cl). The water samples were obtained in the months of March to August. Among 6 sampling months March-May is considered as pre-monsoon season and June-August is considered as monsoon season in Pakistan (Naheed *et al*., 2013).



Legend: Z-I: Zone I; Z-II: Zone II; Z-III: Zone III

Fig. 1. Locations of selected sampling stations across the three zones.

They were examined for nine physicochemical parameters which include pH, electrical conductivity (EC), dissolved oxygen (DO), turbidity, hardness, alkalinity, total dissolved solids (TDS), total suspended solids (TSS) and residual chlorine. Furthermore, microbial analysis of water samples was conducted to evaluate water quality.

Sampling procedures. The samples were collected in 500 mL autoclaved bottles according to WHO recommendations for monitoring microbiological and physico-chemical characteristics in drinking water. Water samples were stored in an icebox (maintaining temperatures between 4-6 °C) and transported to the laboratory for immediate or refrigerated analysis. They were either examined immediately after collection or stored in the refrigerator until analysis. Triplicate water samples were collected to confirm the findings. All procedures were carried out in accordance with the Standard Methods for Water and Wastewater Examination APHA (2017).

Analysis of physico-chemical parameters. To ensure the quality of drinking water, various physico-chemical parameters were monitored. Potable HACH 156 pH meter, Crison Oxi 45 DO meter and conductivity meter 3210 were used for onsite monitoring of pH, DO and EC respectively.

Collected samples were then transported to the laboratory, where they were analyzed for residual chlorine (Titration), turbidity (Portable Turbidimeter HACH 2100P), hardness (Titration), alkalinity (Titration), total dissolved solids (TDS) and total suspended solids (TSS) were determined using Gravimetric method following APHA (2017) guidelines.

Bacteriological analysis. Total and faecal coliform bacteria were assessed using the Most Probable Number (MPN) method, following APHA Standard Methods (2017). Water samples were incubated in Lauryl Tryptose Broth (Oxoid, UK) at 37 °C for 24 h for total coliforms and 44.5 °C for 24 h for faecal coliforms. Confirmatory

Table 1. Longitudes and latitudes of selected sampling stations

Sampling stations	Sampling stations	Latitude and longitude
Z-I	Underground water storage tank (raw water) Overhead water storage tank (chlorinated water)	33°38'48.3"N 72°58'53.3"E
Z-II	Underground water storage tank (raw water) Overhead water storage tank (chlorinated water)	33°38'08.6"N 72°59'17.1"E
Z-II	Underground water storage tank (raw water) Tap water (chlorinated water)	33°38'30.4"N 73°00'13.6"E

tests were conducted using Brilliant Green Bile Broth (Merck, Germany).

Data analysis. Pearson's co-relation matrix was performed to evaluate linear relationship between two physico-chemical parameters in both seasons. Statistical analysis was performed to assess the significant differences in water quality between underground and overhead storage tanks both seasons. For this purpose, a paired *t*-test was performed at 0.05 significance level (95% confidence level) using Microsoft excel 365. Moreover, Principal Component Analysis (PCA) was also performed by using MVSP software to evaluate the variations in data.

Results and Discussion

The results of physico-chemical and bacteriological parameters of samples from selected sampling stations were compared with prescribed limits of WHO and PSDWQ. Physico-chemical parameters were found within the limit except TSS, DO and residual chlorine. Moreover, all the water samples were found highly contaminated with *E. coli*.

Physico-chemical parameters. pH: The pH level in drinking water is a crucial indicator of both water quality and its potential impact on human health (Praveena *et al*., 2024). Fig. 2 illustrates that, the pH values of all water samples were within the limits set by WHO and PSDWQ standards. Specifically, the pH of raw water collected from underground storage tanks ranged from 6.85 to 7.68, while the pH of chlorinated water from overhead storage tanks ranged from 6.85 to 7.62. During the pre-monsoon season, the highest pH (7.68) was recorded in raw water from the underground storage tank of Z-I in April, while the lowest pH (6.85) was observed in chlorinated water from the overhead storage tank of Z-II in May. In the monsoon season, the highest pH (7.62) was found in chlorinated water from the overhead storage tank of Z-I, while the lowest pH (7.03) was observed in raw water from the underground storage tank of Z-III. No significant differences in pH values were observed between the pre-monsoon and monsoon seasons, nor between raw and chlorinated water samples. The observed pH ranges were consistent with findings from a similar study in Bangladesh, where the pH of drinking water from selected primary schools ranged from 6.9 to 8.3, aligning with the current study's results (Kormoker *et al*., 2022). This suggests that the pH levels in both raw and chlorinated water are generally stable and meet the WHO and PSDWQ guidelines.

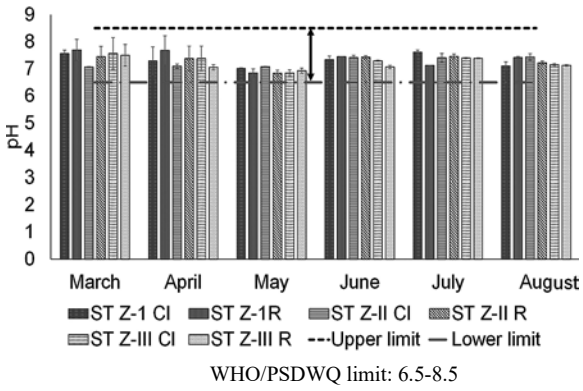


Fig. 2. Seasonal Variation in pH profile of selected sampling stations.

The minor variations in pH values between raw and chlorinated water, as well as between seasons, may be attributed to factors such as temperature changes, microbial processes and air exposure. Temperature fluctuations can affect the solubility of gases and the pH of water. Additionally, microbial activity and the presence of certain materials in the tanks can contribute to leaching or corrosion, which may influence pH levels, (Novak and Gunde-Cimerman, 2021; Slavik *et al*., 2020). However, seasonal and storage-related factors can slightly influence pH levels, the values remain within the acceptable limits for drinking water as set by WHO and PSDWQ. Future studies could focus on the impact of other factors such as microbial contamination and tank material on water chemistry to provide deeper insights into water quality dynamics.

Dissolved oxygen (DO): DO is an essential indicator to determine the quality of drinking water as it reflects the ongoing physical and biological activities in the water (Yu *et al*., 2021). Fig. 3 shows that the water DO of all the six sampling stations in every selected month exceeds the permissible limits. The average DO of chlorinated water obtained from overhead storage tank ranged 8.2-9.5 mg/L while the average DO of raw water samples obtained from underground storage tank ranged 8.2-9.3 mg/L. No significant difference was observed between DO values of raw and chlorinated water obtained from underground and overhead storage tanks respectively. Furthermore, during the pre-monsoon season, the maximum DO of 9.5 mg/L was detected in the water of overhead storage tank of Z-I in March and the lowest DO of 8.5 mg/L was observed in the same tank in May. This could be owing to lower temperatures in March, resulting in lesser bioactivity. Similarly,

during the monsoon season, the lowest DO of 8.2 mg/L was detected in overhead storage tanks of Z-I and Z-III in August, while the maximum DO of 9.2 mg/L was observed in the overhead storage tank of Z-III in July. The DO value is high at low temperature and vice versa for high temperature (Boonsong, 2021). However, few samples in July have high DO value despite the high temperature. This may be because the rate of oxygen diffusion from the atmosphere into water can be influenced by factors such as surface agitation and turbulence, which are often greater at higher temperatures (Boyd, 2020). There are irregular fluctuations in water as it moves from tubewells to underground water storage tanks and finally to overhead storage tanks. So, the level of DO increases with temperature in a few samples. A comparable study by Kamal and Hashmi, (2021a) on university's tap water in Pakistan revealed that the mean DO values of water samples from the selected sampling locations exceeded the limits set by WHO and PSDWQ (Kamal and Hashmi, 2021a).

Electrical conductivity (EC): The total concentration of ionic species in water may be measured by measuring its electrical conductivity. Increase in concentration of ions increases the water electrical conductivity (Meride and Ayenew, 2016). Drinking water has been classified into three categories based on convention: (i) suitable for human consumption (EC<800 µS/cm), (ii) conditionally safe for human consumption (EC=800-2500 µS/cm) and (iii) not recommended for human use (EC>2500 µS/cm) (Rahman *et al*., 2015). The measured conductivity of all the samples was within the limit set by WHO and PSDWQ *i.e.* 2500 µS/cm in both seasons. Fig. 4 illustrates that the average value of electrical conductivity for raw water ranged from 847-1121 µS/cm, while the average value of electrical conductivity for chlorinated water ranged from 860-1107 µS/cm. There is no significant difference between the average values of EC of raw and chlorinated water. Moreover, during the pre-monsoon season, the highest EC of 1107 µS/cm was recorded in water obtained from overhead storage tank of Z-II in May, while the lowest EC of 904 µS/cm was observed in the water obtained from underground tank of Z-III in March. Similarly, during the monsoon season, the greatest EC of 1121 µS/cm was recorded in the water of underground storage tank of Z-II in June, while the lowest EC of 847 µS/cm was recorded in the water of underground storage tank of Z-III in August. This shows that the chlorinated water of Z-II in May and raw water obtained from underground storage tank of same zone in June has the maximum value of total dissolved solids (TDS) during pre-monsoon and monsoon season respectively. These variations in EC reflect the levels of total dissolved solids (TDS) in the water, as EC and TDS are directly related. TDS measures the total concentration of both inorganic and organic substances dissolved in water, whereas EC quantifies the water's ability to conduct electricity, which increases with the concentration of dissolved ions (Bakhtiar *et al*., 2019). In this study, the highest EC values of chlorinated water in Z-II during the pre-monsoon season and raw water in Z-II during the monsoon season correspond to the highest TDS values for each season. A potential factor contributing to the elevated EC values in the study could be corrosion in the metal pipes used for water transport from tube wells to storage tanks. Corrosion can introduce additional ions into the water, leading to higher EC readings and possibly increasing the accumulation of heavy metals (Novak and Gunde-Cimerman, 2021). These findings align with the results of a study by Javed *et al*. (2021), which found that the

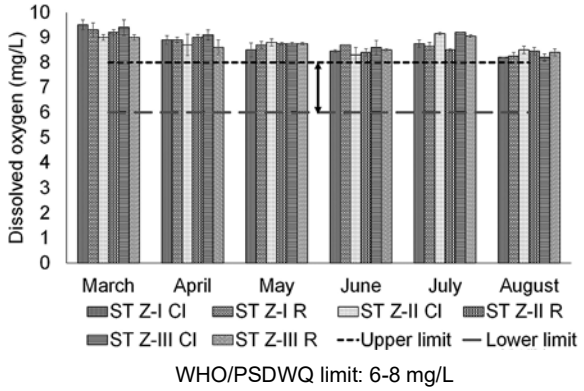


Fig. 3. Seasonal variation in DO profile of selected sampling stations.

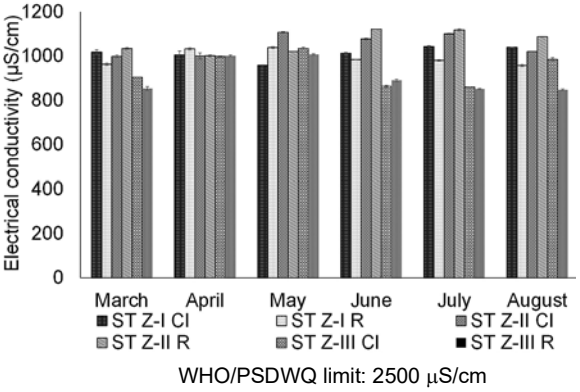


Fig. 4. Seasonal variation in EC profile of selected sampling stations.

EC of water samples from Saggiyan, Lahore, ranged from 298 to 468 µS/cm, also within the prescribed limits. EC values observed in this study reflect typical water quality conditions, with no significant differences between raw and chlorinated water samples. The observed EC values are within the safe range for drinking water, but factors like corrosion may contribute to occasional increases in EC and TDS.

Turbidity. Turbidity is defined as the amount of solid suspended particles present in water. It is an estimate of light emitting properties of water (Meride and Ayenew, 2016). Fig. 5. illustrates that the drinking water turbidity of all the samples varies in every selected month but within the prescribed limit of WHO/PSDWQ. The average value of turbidity for raw water (Fig. 5) ranged from 0.64-1.86 NTU, while average value of turbidity for chlorinated water ranged from 0.78-2.81 NTU. During the pre-monsoon season, the highest turbidity of 2.81 NTU was recorded in water collected from overhead storage tank of Z-I in March, while the lowest turbidity of 0.64 NTU was observed in water collected from underground storage tank of same zone in May. Similarly, during the monsoon season, the greatest turbidity of 1.86 NTU was recorded in the overhead storage tank of Z-II in July, while the lowest turbidity of 0.65 NTU was recorded in the underground storage tank of Z-I in June. The variation of turbidity values in few samples may be due to the leakage in distribution pipes through which water from tube wells was directed towards storage tanks or corrosion of tanks and pipe material leading to amplify the quantity of particulate matter in drinking water. Although turbidity levels in water samples were found to be within permissible limits in both seasons, turbidity levels less than 1 NTU are generally considered acceptable for efficient chlorination, as higher turbidity can shield microorganisms from the disinfectant and interfere with inactivation (Leziart *et al*., 2019). Results of current study are align with study conducted in 2019 in which turbidity values of tap water samples collected from selected five locations in Bidar district of India, turbidity was fall in the range of 0.5-2.85 NTU which was within the acceptable range (Lina *et al*., 2019).

Hardness. Hardness in drinking water is determined by the presence of divalent metal ions such as calcium (Ca^{2+}) and magnesium (Mg^{2+}) (Ghani *et al*., 2019). In this study, raw water samples exhibited hardness levels ranging from 296-410 mg/L, while chlorinated water samples ranged from 338-401 mg/L. Fig. 6, shows that hardness values varied monthly in both seasons but remained within the limits set by WHO and PSDWQ. The natural accumulation of salts through continuous interaction with soil and geological formations primarily contributes to water hardness (Lina *et al*., 2019).

During the pre-monsoon season, the lowest hardness (341 mg/L) was recorded in the underground storage tank of Z-III in April, while the highest (410 mg/L) was observed in Z-I in May. In the monsoon season, hardness levels ranged from 296 mg/L in Z-III (June) to 400 mg/L in the overhead storage tank of Z-I (July). These findings are consistent with the study by Yeboah *et al*. (2022), which reported intake water hardness between 120-360 mg/L and consumer-end water hardness between 40-620 mg/L in the Tano north municipality, Ghana, while intake water remained within WHO and PSDWQ limits, some consumer-end sources exceeded recommended levels, highlighting potential variations due to distribution and storage conditions.

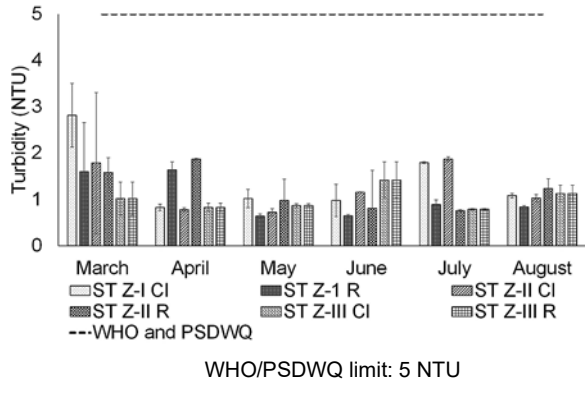


Fig. 5. Seasonal variation in turbidity profile of selected sampling stations.

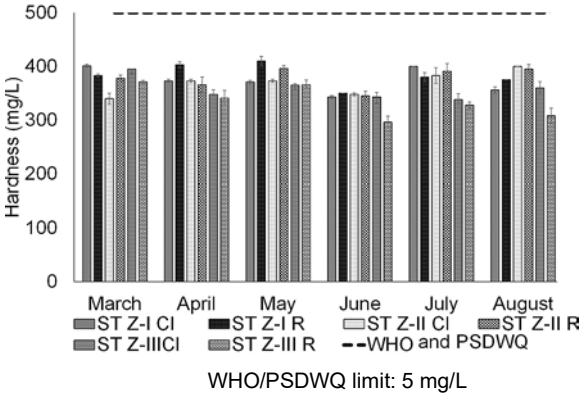


Fig. 6. Seasonal variation in hardness profile of selected sampling stations.

Total dissolved solids (TDS). A variety of inorganic minerals, such as potassium, magnesium, calcium, chlorides, sodium, sulphates and bicarbonates are dissolved in water. These minerals contribute to unwanted taste and alter appearance (Kumar *et al*., 2022). As TDS increases, water taste suitability decreases (Devesa and Dietrich, 2018). TDS and electrical conductivity (EC) are closely linked, both serving as indicators of mineral content and water quality. TDS values in all water samples were within the WHO and PSDWQ limit of <1000 mg/L. Chlorinated water had TDS ranging from 448-575 mg/L, while raw water ranged from 440-583 mg/L. During the pre-monsoon season (Fig.7), the lowest TDS (442 mg/L) was observed in the underground storage tank of Z-III in March and the highest (575 mg/L) in the overhead storage tank of Z-II in May. In the monsoon season, the lowest TDS (440 mg/L) was recorded in the under-ground storage tank of Z-III in August and the highest (582 mg/L) in the underground storage tank of Z-II during June and July. These results align with a study in Peshawar, where TDS values at water sources ranged from 371-680 mg/L and at consumption sites, from 454-700 mg/L, all within the WHO and PSDWQ limits (Yousaf *et al*., 2019). The correlation between EC and TDS confirms their role as indicators of mineral content and water quality.

Residual chlorine: Chlorine serves as a highly effective disinfectant for removing viruses and pathogenic bacteria (Abbas, 2011). Its ability to maintain a residual effect throughout the distribution system is critical for preventing microbial regrowth and ensuring safe drinking water. Fig. 8 illustrates that residual chlorine levels in all drinking water samples from selected sampling stations vary from month to month. For optimal disinfection and purification of drinking water, WHO and PSDWQ suggest that the amount of residual chlorine at the source should be between 0.5 and 1.5 mg/L and at the consumer end, it should be between 0.2 and 0.5 mg/L. All water samples were found to have residual chlorine levels below the WHO and PSDWQ limits in both seasons at the source. No chlorine was added to underground water storage tanks, but in the present study, trace amounts of residual chlorine were detected (Fig. 8) in raw water from a few sampling stations, likely due to the residual effect of periodic tank cleaning. The residual chlorine levels in raw water ranged from 0-0.12 mg/L, which is almost negligible, indicating that during the selected months, drinking water from underground storage tanks at all selected sampling stations may be susceptible to microbial contamination, making it unsuitable for direct consumption.

Whereas residual chlorine in chlorinated water ranged from 0-0.48 mg/L, which is also below the prescribed limit. This consistently low residual chlorine concentration suggests that the chlorine demand of the water is high, possibly due to the presence of organic matter or other reactive substances in the storage tanks. During the pre-monsoon season, no residual chlorine content was detected in the chlorinated water of Z-III in April, while the highest residual chlorine level was observed in the chlorinated water of Z-III at 0.29 mg/L in March. Similarly, during the monsoon season, no residual chlorine content was detected in the water from the overhead storage tank of Z-II in August, while the highest residual chlorine value was detected in water from the overhead storage tank of Z-I in August.

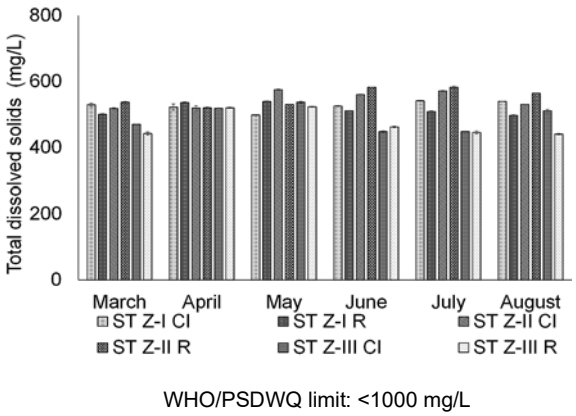


Fig. 7. Seasonal variation in TDS profile of selected sampling stations.

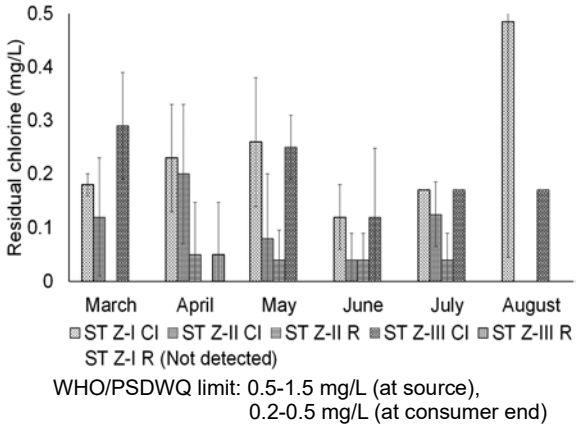


Fig. 8. Seasonal variation in residual chlorine profile of selected sampling stations.

Chlorine is used for water disinfection due to its residual effect, which continues to act even after being introduced into the water (Madzivhandila and Chirwa, 2017). However, in the present study, residual chlorine levels were significantly lower than WHO and PSDWQ guidelines, indicating that the disinfection process may not be effectively maintaining chlorine levels over time. This could be attributed to chlorine reacting with organic and inorganic compounds present in water storage tanks before interacting with the water itself, leading to a reduction in its overall concentration. Furthermore, variations in residual chlorine levels among different sampling points suggest inconsistent chlorine dosing or potential loss due to volatilization and degradation over time, particularly in open or semi-closed storage systems. Moreover, chlorine that reacts with organic matter forms disinfectant by-products like trihalomethanes, which are even more hazardous to human health (Vargas *et al*., 2021). These results align with a previous study conducted in Sharjah, which analyzed water quality variations from the main supply to building water storage tanks. The results showed that 30% of water samples had residual chlorine levels below 0.2 mg/L (Semerjian *et al*., 2021). Therefore, the observed low chlorine levels highlight the need for improved chlorine dosing strategies, routine monitoring, and enhanced storage tank management to ensure consistent and effective disinfection throughout the system.

Alkalinity: The parameter of alkalinity is used to evaluate the capacity of bases to neutralize acids and represent as buffering capacity of water. Total alkalinity of drinking water is due to the presence of hydroxide compounds, carbonate and bicarbonate. Alkalinity values for all samples (Fig. 9) vary from month to month but were within the prescribed limit *i.e*. 500 mg/L. The variation in the values of alkalinity may be due to environmental factors and human activities. Moreover, the leaching and corrosion of pipe material used may produce the substances which can fluctuate the alkalinity values of water (Batarseh, 2006; Valentukeviciene *et al*., 2013). The alkalinity of raw water ranged from 295-400 mg/L while the alkalinity of chlorinated water ranged from 335-401 mg/L. During pre-monsoon season the lowest alkalinity of 335 mg/L was observed in water sample collected from overhead storage tank of Z-II, while highest alkalinity of 390 mg/L was observed in water of overhead storage tank of Z-I in March. Similarly, in monsoon season the lowest alkalinity of 328 mg/L was observed in water of overhead storage tank of Z-I, while highest alkalinity of 407 mg/L in water of overhead storage tank of Z-II in July. These results are consistent with study conducted by Javed and coworkers, 2021 in which microbial contamination in drinking water of Saggiyan Lahore, Pakistan was assessed. The results showed that average alkalinity in all water samples was ranged between 169-290 mg/L which is within the prescribed limit of WHO and PSDWQ (Javed *et al*., 2021).

Total suspended solids (TSS). TSS are mainly solids that are insoluble and may present in suspended form hence causes turbidity (Choudhury *et al*., 2016). It is a quality parameter that can affect the aesthetic quality of water, its treatment processes and can serve as a medium for the transmission of bacteria and other contaminants (Jurek and Heviánková, 2021). The TSS of drinking water samples showed variations in each month. The acceptable limit for TSS recommended by WHO and PSDWQ in drinking water is 5 mg/L. TSS for both chlorinated and raw water ranged from 0-16.6 mg/L. During the pre-monsoon season, no TSS were detected in the water from the underground storage tank of Z-I in May. However, the highest TSS value of 16.6 mg/L was recorded in March in the overhead storage tank of Z-I and in April in the underground storage tank of Z-III. Similarly, during monsoon season no TSS was detected in water collected from under-ground storage tank of Z-I and chlorinated water of Z-III in June and July respectively, while highest TSS value of 15 mg/L was observed in water collected from underground storage tank of Z-III in August. All water samples have TSS values greater than the recommended limit (Fig. 10) in both the seasons except chlorinated water sample of Z-II in the month of April and July. The TSS values were found to exceed the prescribed limits set by WHO and PSDWQ in the drinking water samples of District Bajaur, Pakistan,

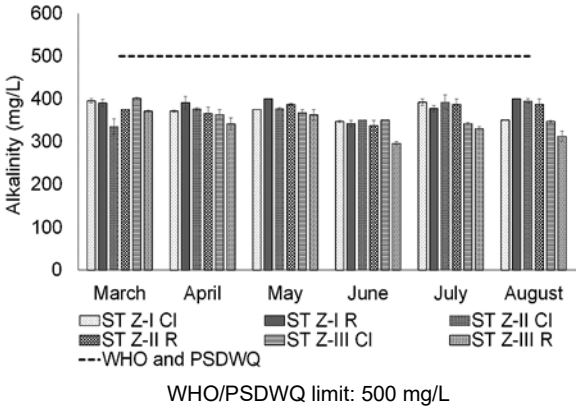


Fig. 9. Seasonal variation in alkalinity profile of selected sampling stations.

which is consistent with the findings of the current study (Khan *et al*., 2021).

Bacteriological analysis. Coliform bacteria, particularly *E. coli*, are used as indicator organisms to assess microbial contamination in water, with their presence posing significant health risks due to waterborne diseases (Vunain *et al*., 2019; Rahman *et al*., 2015). The levels of total and faecal coliforms in water samples from all six sampling stations fluctuated across the months, highlighting a significant microbial contamination issue. According to WHO and PSDWQ guidelines, the permissible limit for both total and faecal coliforms in drinking water is 0 MPN/100 mL. However, Table 2 shows that, the levels of total and faecal coliforms in both raw and chlorinated water samples consistently exceeded this limit.

The MPN index for raw water ranged from 16 to >23, while chlorinated water samples had MPN values ranging from 2.2 to >23. Notably, the raw water from the Z-I storage tank in March had the lowest MPN value (16) with a probability range of 5.8-34, likely due to the use of chlorine as a disinfectant at that time. Despite this, all other raw water samples showed MPN values of 23 or greater, with a 95% probability range of 13 and above. The chlorinated water from Z-I also showed lower MPN values, but the presence of coliform bacteria was still significant, ranging from 2.2 to >23.

Chlorination is typically employed to remove bacterial contamination from water, making it safe for drinking. Ideally, chlorination should result in a significant reduction of the MPN index, but in this study, bacterial

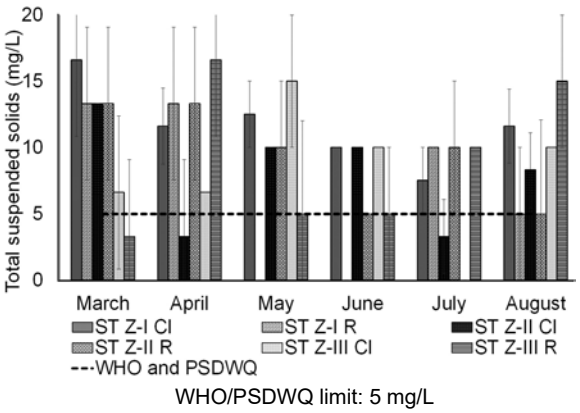


Fig. 10. Seasonal variation in TSS profile of selected sampling stations.

contamination was not eliminated. The levels of free chlorine at the consumer end were found to be insufficient, with residual chlorine values far below the recommended range of 0.5-1.5 mg/L, contributing to the continued presence of coliforms even after chlorination. This suggests that the chlorination process was not fully effective in disinfecting the water. Microbial contamination of water is a critical health concern, as it can lead to the spread of waterborne diseases. The results from both the pre-monsoon and monsoon seasons indicate ongoing bacterial contamination, likely due to inadequate chlorination. These findings are consistent with the study by Kamal and Hashmi, (2021b) which also observed that the MPN index for both raw and chlorinated water exceeded the prescribed limits in drinking water, further reinforcing

Table. 2. Seasonal variation in MPN index of selected sampling station

		WHO and PSDWQ limit: 0 MPN/ 100 mL					
Months	MPN Index/ 100 mL	Z-I		Z-II		Z-III	
		ST1 R	ST1 Cl	ST2 R	ST3 Cl	ST3 R	ST3 Cl
March	MPN Index	16	9.2	23	9.2	23	2.2
	95% Probability range	5.8-34	3.3-19	8.1-53	3.3-19	8.1-53	0.37-8.2
April	MPN Index	>23	2.2	>23	12	>23	23
	95% Probability range	13-…..	0.37-8.2	13-….	4.8-24	13-…	8.1-53
May	MPN Index	>23	6.9	23	23	>23	23
	95% Probability range	13-…..	2.5-15	8.1-53	8.1-53	13-….	8.1-53
June	MPN Index	>23	5.1	>23	>23	>23	23
	95% Probability Range	13-…..	1.6-13	13-….	13-….	13-….	8.1-53
July	MPN Index	>23	5.1	23	9.2	>23	2.2
	95% Probability Range	13-…..	1.6-13	8.1-53	3.3-19	13-….	0.37-8.2
August	MPN Index	>23	3.6	>23	>23	>23	9.2
	95% Probability Range	13-…..	0.91-9.7	13-….	13-….	13-…..	3.3-19

the need for improved disinfection practices. The microbial contamination of drinking water remains a significant health concern in this study area, as evidenced by the consistently high MPN values for total and faecal coliforms. This highlights the urgent need for better water treatment processes, particularly effective chlorination, to ensure safe drinking water for the community.

Statistical analysis. *Pearson's correlation matrix.* The relationship between two variables is referred to as correlation. Correlation coefficient between water parameters can be calculated systematically to provide valuable means for quick water monitoring. The relationship is strongest when the variables fall within the range of +0.8 to +1.0 or -0.8 to -1.0. Similarly, when variables are in ranges of +0.5 to +0.8 and -0.5 to -0.8 correlation is moderate and when parameters are in range of +0.0 to +0.5 and -0.0 to -0.5 the correlation is poor (Khan *et al*., 2023).

A strong correlation exists among various physico-chemical parameters and their combined influence reflects the overall water quality (Daraigan *et al*., 2011). Fig. 11 and 12 show the values of Pearson's correlation coefficient for physico-chemical parameters of drinking water for both the seasons (pre-monsoon and monsoon) respectively. EC and TDS of water samples showed the best correlation *i.e.* r=0.99 with P-values 5.83×10-11 and 2.62×10-9 for both the seasons respectively. Similarly, DO and temperature show the strong negative correlation r=-0.83, r=-0.80 with P-value 0.01 during pre-monsoon and P-value equals to 0.05 during monsoon season. Moreover, Alkalinity and hardness show strong correlation with r=0.98, r=0.95 with P-values 0.003 and 0.0002 in both the seasons respectively. pH and alkalinity also showed strong correlation with r=0.93, r=0.95 with P-values 0.003 and 0.005 during both the seasons respectively. Similarly, TSS and turbidity show the strong correlation r=0.84, r=0.86 with P-values 0.03 and 0.02 in both the seasons respectively. Hardness shows strong correlation with pH having r=0.90, r=0.96 with P-values 0.01 and 0.002 in both the seasons respectively.

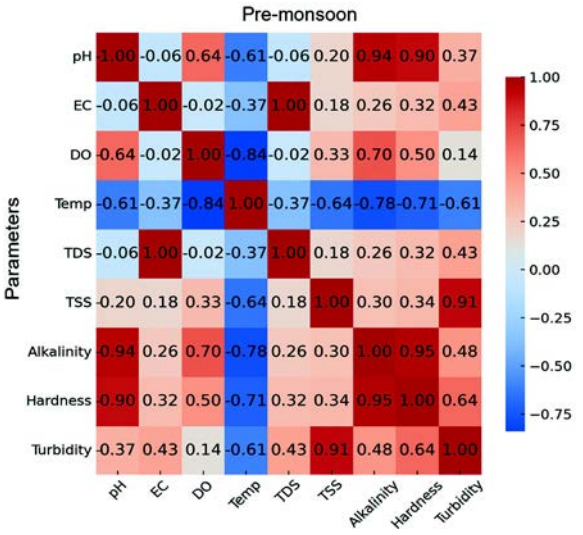


Fig. 11. Pearson's co-relation matrix of drinking water samples.

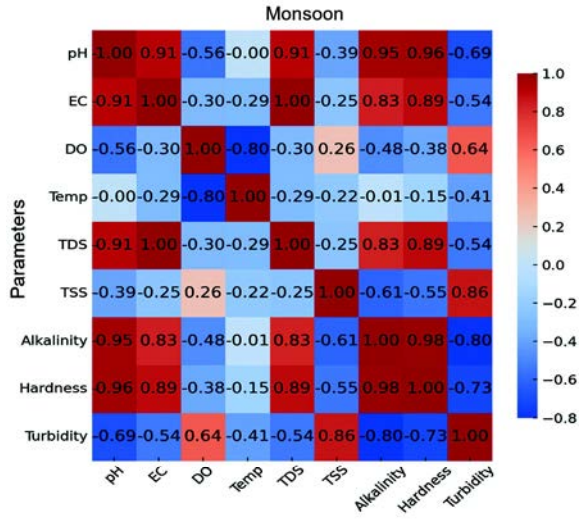


Fig. 12. Pearson's co-relation matrix of drinking water samples.

Principal component analysis (PCA). *Pre-monsoon and monsoon seasons.* Principal component analysis (PCA) of pre-monsoon and monsoon seasons, including six sampling stations and nine parameters, is presented in Table 3. In the pre-monsoon season, the first three principal components (PCs) account for 87.94% of the total variance, while in the monsoon season, they explain 91.44%. Eigenvalues greater than 1 confirm that PC1 contributes the most to data variation. The first two PCs explain over 70% of the variance in the pre-monsoon season and more than 80% in the monsoon season. Alkalinity is the dominant variable in PC1 across both seasons, with EC and TDS influencing PC2 in the pre-monsoon season, while temperature plays a key role in PC2 during the monsoon season. Residual chlorine is a significant factor in PC3 for both seasons. CA biplots (Fig. 13 and 14) reveal strong positive correlations between pH and alkalinity, alkalinity and hardness, pH and hardness, as well as TSS and turbidity, while DO

and temperature exhibit a strong negative correlation. The dispersion of sampling sites on the biplot indicates no distinct spatial or temporal clustering. The pronounced length of the residual chlorine vector suggests its sharp fluctuations, which may significantly impact water quality.

Paired *t*-test. Results showed that P-value of residual chlorine of Z-I is 0.04 in pre-monsoon season and of Z-III is 0.007 in monsoon season are significantly less than 0.05. Additionally, the critical value of residual chlorine was lower than the measured t-statistic for both Z-I and Z-III in their respective seasons. This indicates a significant difference in residual chlorine levels between underground and overhead storage tanks in these zones.

For all other parameters, the P-value exceeded 0.05, suggesting no significant difference between water samples from underground and overhead storage tanks during both seasons (Table 4). This may be due to the low chlorine detection in most samples, except for Z-I in the pre-monsoon season and Z-III in the monsoon

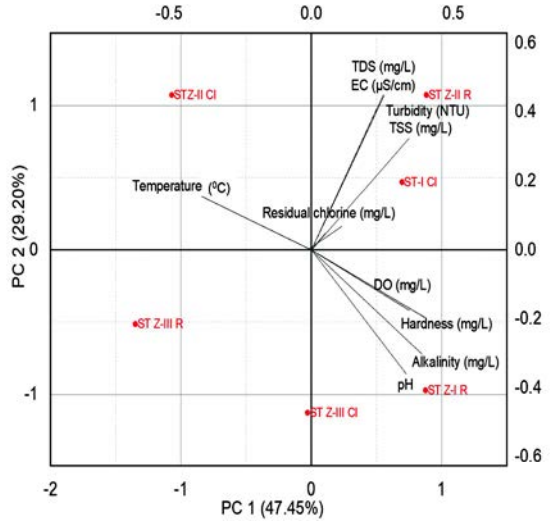


Fig. 13. PCA ordination plot with samples (points) and water quality variables (Pre-monsoon).

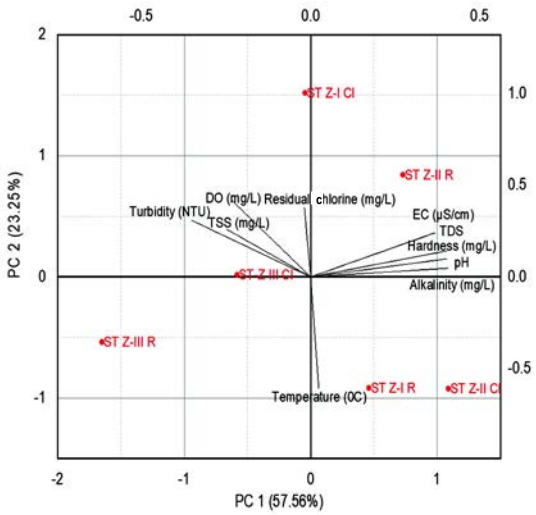


Fig. 14. PCA ordination plot with samples (points) and water quality variables (Monsoon).

Table. 3. Principal component loadings for water quality parameters of samples
PM: Pre-monsoon, M: Monsoon
*Important variables for variation in PC1, PC2 and PC3

Parameters	PC1		PC2		PC3	
	PM	M	PM	M	PM	M
pH	0.341	0.402	-0.388	-0.098	-0.118	0.214
EC (µS/cm)	0.185	0.367	*0.529	-0.240	-0.366	0.003
DO (mg/L)	0.315	-0.233	-0.266	-0.417	0.214	-0.496
Temp (°C)	-0.414	0.024	0.003	*0.610	-0.060	0.351
TDS (mg/L)	0.186	0.367	*0.529	-0.241	-0.366	0.004
TSS (mg/L)	0.282	0.249	0.213	-0.261	0.505	0.507
Alkalinity (mg/L)	*0.404	*0.407	-0.195	-0.048	-0.171	0.011
Hardness (mg/L)	0.393	0.403	-0.141	-0.142	-0.243	-0.012
Residual chlorine (mg/L)	0.086	-0.018	0.283	-0.379	*0.550	*0.530
Turbidity (NTU)	0.374	-0.352	0.189	-0.309	0.232	0.216
Eigenvalues	5.066	5.756	2.152	2.325	1.576	1.070
Percent variance	50.664	57.55	21.517	23.252	15.761	10.700
Cumulative percent variance	50.664	57.55	72.181	80.809	87.943	91.509

Table 4. P-values from the two-tailed t-test for the physico-chemical parameters across all three zones

Sampling stations	pH		DO (mg/L)		EC (µS/cm)		Turbidity (NTU)		Hardness (mg/L)		Alkalinity (mg/L)		TSS (mg/L)		TDS (mg/L)		Residual Cl (mg/L)	
	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M	PM	M
Z-I	0.79	0.29	0.69	0.57	0.70	0.06	0.67	0.16	0.40	0.90	0.28	0.66	0.37	0.89	0.69	0.06	0.04	0.14
Z-II	0.25	0.45	0.28	0.48	0.69	0.09	0.37	0.15	0.30	0.42	0.45	0.06	0.42	0.39	0.69	0.08	0.07	0.42
Z-III	0.31	0.92	0.28	1	0.35	0.51	0.94	0.67	0.29	0.14	0.20	0.44	0.74	0.49	0.35	0.52	0.39	0.007

PM: Pre-monsoon, M: Monsoon

season. Despite the observed difference in residual chlorine between underground and overhead storage tanks in these zones, the chlorine levels remained below the WHO and PSDWQ recommended limits.

Conclusions

The results of this study showed that all water samples fail to comply with the WHO or PSDWQ for drinking water quality in terms of total and fecal coliforms owing to lower chlorine level in both raw and chlorinated water. However, the physicochemical parameters in all samples were within the permissible limit of WHO and PSDWQ guidelines, except for turbidity, TSS and DO. Moreover, Pearson's co-relation matrix of both seasons showed strong co-relation among different physico-chemical parameters of all samples and their inter-relationship concludes that water is not suitable for drinking purposes. Principal component analysis (PCA) showed that residual chlorine contents are a major parameter of causing variation in water quality. Additionally, the paired t-test revealed that there is no statistically significant difference between the water from underground and overhead storage tanks in pre-monsoon and monsoon season in most samples. The findings of this study strongly suggest implementing regular monitoring and accurate chlorine dosing, along with the installation of advanced filtration systems, to ensure the safety of potable water.

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Conflict of Interest. The authors declare that they have no conflict of interest.

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