Drinking water quality monitoring of centralized water storage reservoirs in various zones of the National University in semi-arid region of Pakistan

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Abstract

Physico-chemical and microbiological pollutants may compromise quality of drinking water. The current study aims at highlighting various physico-chemical and microbial parameters of drinking water samples collected from centralized water storage reservoirs of National University. Major water quality parameters which were examined in this study include pH, Electrical conductivity (EC), Turbidity, Total suspended solids (TSS), Total dissolved solids (TDS), Dissolved oxygen (DO), Residual chlorine, Hardness, Alkalinity. Moreover, microbial analysis of water samples was also carried out through Most Probable Number technique (MPN). Results indicate that all the physico-chemical parameters were within prescribed limits of World Health Organization and Pakistan Drinking Water Quality Standards (WHO/PDWQS) in both underground and overhead water storage reservoirs except DO (9.05-9.2 and 9.05-9.1 mg/L), TSS (10-20 and 3.3-10 mg/L) and residual chlorine (0.08-0.14 and 0.19-0.28 mg/L), respectively. The MPN index values for both underground and overhead water storage reservoirs range between 16- >23 and 1.1-12, respectively, which illustrates high microbial contamination in water due to low detection of residual chlorine. The results highlight that water from centralized water storage reservoirs of National University is unfit for drinking purposes. Statistical analysis such as paired t-test also reveals that water quality parameters from underground and overhead storage reservoirs are not significantly different from each other except EC and TDS having P values <0.05. It is necessary to safeguard water quality in water storage reservoirs by regular inspections and chemical cleaning of water storage reservoirs otherwise it will cause serious threats to well-being of the community.

Key words: water storage reservoirs, drinking water, microbial quality of water, physico-chemical parameters, paired t-test.

Introduction

The goal of centralized drinking water treatment and distribution systems is to provide consumers with potable drinking water yet, this system is the most complex because distribution networks contain complex microbiological organisms [1]. Access to clean potable water is crucial to human health, development, and well-being [2]. However, scarcity of potable water poses a grave challenge to populace throughout the world. About 80% of all waterborne illnesses caused by contaminated drinking water are the consequence of anthropogenic activities [3]. Rapid, unplanned urbanization and industrialization are significant contributors to water pollution. About 1 billion people around the globe have access to clean drinking water [4]. For various species, including bacteria, viruses, and protozoa that are detrimental to human health, water is thought to behave as a passive carrier [5]. Regarding drinking water, bacterial contamination poses a serious health danger [3]. Factors such as source, distribution, transportation of water or domestic handling, hygiene, and sanitation practices may all contribute to microbial contamination of water [6]. The principal causative agent of waterborne maladies include diarrheal illness, shigella, typhoid, hepatitis A/E and polio are pathogenic bacteria [3]. Each year, around 842000 people succumb to diarrhea as a result of contaminated water. About 663 million people are thought to still rely on unimproved water sources for drinking [7,8]. Likewise, 1.8 billion people worldwide consume contaminated water [9]. For a sustainable community, pollution reduction must be considered as a prime concern [10]. Sustainable Development Goal 6 (SDG) emphasizes the significance of clean and safe drinking water for everyone and relates to reducing pollution, improving water quality, and dealing with the issue of water scarcity [11]. In developing nations like Africa, South Asia, and South East Asia, 529 million people lack access to potable water resources [8].

Pakistan is a developing country with compromised sanitary conditions attributed to poverty and lack of knowledge [12]. According to an estimate, waterborne diseases are a serious predicament for the population; only 47% of households have access to clean drinking water, and only 61% have safe sanitation systems [13]. It is estimated that 110 children per day in Pakistan pass away from diseases associated to Water, Sanitation and Hygiene (WASH) [7]. Lack of knowledge, improper scientific research, and a lack of resources are the main causes of Pakistan's rising water quality dilemma. According to the research by International Union for Conservation of Nature (IUCN), water-borne infections, which are most prevalent in Asia, are thought to be the cause of death for 60% of infants in Pakistan [14]. In Pakistan, water is generally not treated or filtered before being supplied for human use. Chlorination is the only treatment being used to clean and disinfect drinking water sources and coliform populations in Pakistan. However, research has revealed that even coliform-free drinkable water may contain dangerous human pathogens that can cause water-borne ailments [5,15]. To be considered safe, drinking water must never include excessive levels of harmful substances or pathogens. Drinking water samples were collected from various schools and colleges of Islamabad in

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order to assess water quality. Analysis revealed that among 30 samples 20 were microbiologically contaminated and unfit for drinking [16]. The most common and prevalent concern related to drinking water is microbial contamination. Due to overuse of the groundwater resource, agricultural impact, and direct release of contaminants, a study of bore wells and open wells in Rawalpindi and Islamabad using a Geographic Information System and the Water Quality Index revealed that more than half of the samples were unfit for human consumption [17]. Natural streams that are located in the capital city have poorer water quality. Due to the high levels of total and faecal coliform bacteria in water reservoirs, effective water treatment is needed for drinking and domestic use [18]. According to the results of the heterotrophic bacterial assessment of the drinking water quality of tube wells, water reservoirs, and filtration facilities in different areas of Islamabad, 21% of the 55 samples were contaminated with total coliform, faecal coliform, and E. coli [19]. Quality assessment of drinking water provides significant measure of safety, and the majority of nations have national standards that frequently coincide with WHO drinking water quality recommendations. Availability of good quality of water resources depends on multiple physico-chemical and microbial parameters. The current study aims at highlighting various physico-chemical and microbial quality of drinking water from centralized water storage reservoirs of a National university to understand the status of water supply to university's community.

Study site

National University named National University of Sciences and Technology (NUST), Islamabad Pakistan is a public sector research university and covers an area of 707 acres having more than 15 schools and institutes, faculty residence and hostels for both male and female students. The water distribution system of university is serving approximately 20,000 people including day scholars, hostelites, faculty and staff. Monitoring of the physico-chemical and microbial composition of drinking water is crucial as universities are at risk due to limited access to potable water. It increases students' vulnerability to environmental health hazards and makes for high-risk environment for university's residents. It also enhances the people susceptibility to environmental health risks posed by contaminated drinking water [20]. Hostelites, day scholars, faculty and staff who spend most of the time in university depend on university's water supply and they often suffer from waterborne diseases which increases the rate of absentees and decreases the overall efficiency and productivity of students and staff in terms of academic performance. Therefore, it is necessary to monitor water quality and ensure the community's health around the university in order to suggest remedial measures in case water is unsuitable for drinking.

Materials and methods

National University under study is divided into III zones (I, II, III) and its water distribution system is based on tube wells. Water from tube wells enters underground water storage reservoirs. Each zone has its own centralized underground water storage reservoir which is made up of reinforced concrete cement (RCC).

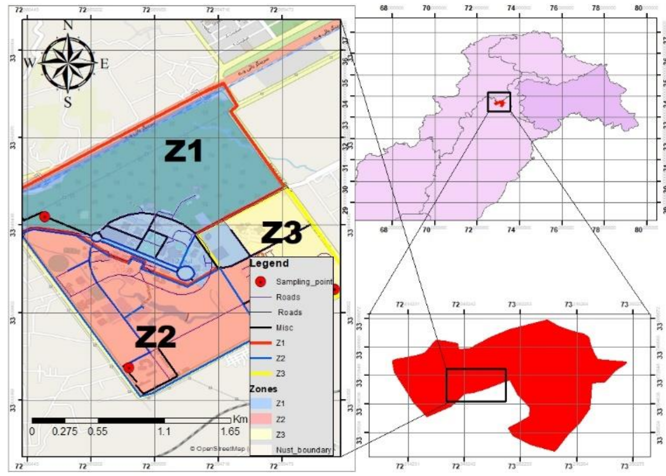

Fig 1: Map of the sampling sites
(Legends: Z-1 Water storage reservoirs zone-I, Z-2 Water storage reservoirs zone-II, Z-3 Water storage reservoirs zone-III)

Water from underground reservoirs is directed to overhead reservoirs and about one parts per million (1ppm) chlorine is added as a disinfectant to remove all the microbial contamination. Z-III has no overhead water storage reservoir and is directed towards drinking water distribution system (DWDS) after chlorination. Water samples were obtained from both underground and overhead reservoirs and zone which has no overhead reservoir. Water sample was also collected from tap besides underground reservoir. Details of centralized water storage reservoirs of the National University is shown in the Table 1.

Table 1: Details of centralized water storage reservoirs of the National University

Sampling sites	**Centralized water storage reservoirs**	**No. of Reservoirs**	**Capacity (Gallons)**	**Storage Gallons**
Zone-I	Underground water reservoirs	2	300,000	600,000
	Overhead water reservoir	1	100,000	100,000
Zone-II	Underground water reservoirs	3	300,000	900,000
	Overhead water reservoir	1	100,000	100,000
Zone-III	Underground water reservoir	1	150,000	150,000
	Overhead water reservoir	-	-	-
	Total Storage	**1,850,000 (Gallons)**		

Samples were collected in the month of February 2021. Samples from both underground and overhead reservoirs were collected for analysis of physico-chemical and microbial parameters. The sampling locations are shown in the Fig 1. Total of 9 physico-chemical parameters were monitored which includes pH, dissolved oxygen (DO), turbidity, total suspended solids (TSS), total dissolved solids (TDS), electrical conductivity (EC), residual chlorine, alkalinity, hardness. Furthermore, microbial quality of water was also analyzed.

Sampling

All water samples were collected in 500 ml sterilized glass bottles according to the guidelines provided by WHO. All the samples were placed in an ice box and immediately exported to the laboratory for analysis. All the procedures including sample collection, physico-chemical and microbial analysis were performed according to Standard Methods for the Examination of Water and Wastewater [21].

Physico-chemical analysis

Analyses of multiple physico-chemical parameters were carried out. Some analyses were performed onsite which includes dissolved oxygen (DO) using CrisonOxi 45 DO meter, pH using potable HACH 156 pH meter, electrical conductivity using Conductivity meter 3210, turbidity using portable turbidimeter HACH 2100P. Hardness and Alkalinity by Titration method, TDS and TSS by Gravimetric method were measured in laboratory.

Microbial analysis

The Most Probable Number (MPN) technique was used to carry out microbial examination of drinking water samples to determine the presence of Fecal coliform, Total coliform and *E. coli*.

Results and discussion

Physico-chemical analysis

Results of physic-chemical and microbial analysis of drinking water quality were compared with WHO/PDWQS. Table 2 shows the prescribed limits of WHO/PDWQS for all physic-chemical and microbial parameters.

Table 2: Prescribed values of WHO/PDWQS for drinking water quality monitoring

Drinking water quality parameters	Standard values	
	WHO [22]	**PDWQS [23]**
pH	6.5-8.5	6.5-8.5
Electrical conductivity (µS/cm)	2500	………
Turbidity (NTU)	<5	<5
Dissolved oxygen (mg/L)	6-8	………
Hardness (mg/L)	<500	<500
Alkalinity (mg/L)	<500	<500
Total suspended solids (mg/L)	5	………
Total dissolved solids (mg/L)	<1000	<1000
Residual chlorine (mg/L)	0.2-0.5	………
MPN/100 ml	0/100	0/100

pH: pH of water samples is a measure of the acid base balance of them. Number of toxic substances in water bodies may be increased or decreased based on the value of pH in water [24]. The pH value of sample obtained from the underground storage reservoir of Z-I was 8.06 which is highest of all the samples obtained from the storage reservoirs. The lowest value of pH was found in overhead reservoir of Z-II. There is not much difference in pH values for both underground and overhead storage reservoirs of Z-III. Increase or decrease of pH in samples from value of 7 may be attributed to imbalance of carbonate and bicarbonate ions in it [20]. All the samples obtained from the storage reservoirs were found to be within the limit prescribed by WHO/PDWQS which is 6.5-8.5 as shown in Fig 2. Fluctuation in temperature may cause change in the pH of samples [19]. Similar study was conducted by Rehmanian and coworkers in 2015 evaluating the pH value of drinking water in state of Perak, Malaysia. The value of pH in all samples was found within the limit set by WHO which is 7.01-8.2 and its similar to results of the current study [26].

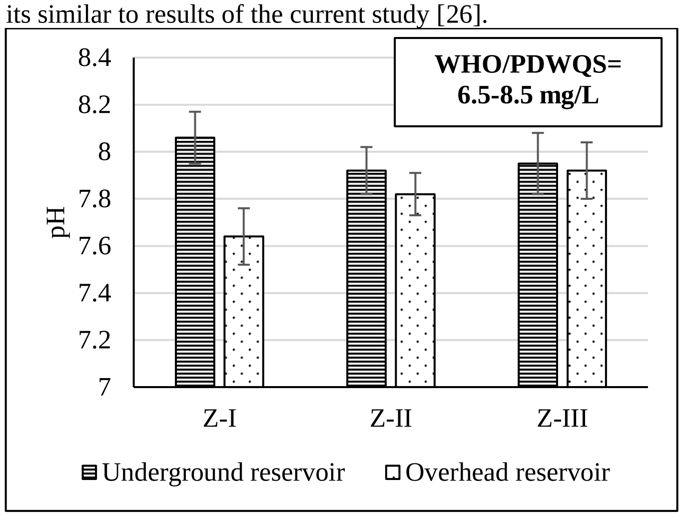

Fig 2: Variation in pH values of underground and overhead water storage reservoirs

Electrical conductivity (EC): Electrical conductivity defines the value of current the water carries. It is also associated to the total dissolved solids (TDS) content of the water [27]. The EC of water samples of underground storage reservoirs ranged between 852-1015 µS/cm and EC of samples obtained from overhead storage reservoirs ranged between 873-949 µS/cm. The highest EC was noted in underground storage reservoir of Z-II and lowest EC was noted in underground storage reservoir of Z-III. The value of EC will increase as the amount of TDS in the water increases [14]. EC values for all the samples of selected sampling stations was within the prescribed limit of WHO which is 2500 µS/cm as shown in Fig 3. Similar study was conducted by Sohaila and coworkers in 2020 in which EC values of samples from public drinking water sources in Rawalpindi and Islamabad, Pakistan was examined. The EC values of all the samples were ranged between 296-1474 µS/cm which is within the limit prescribed by WHO and similar to our study [28].

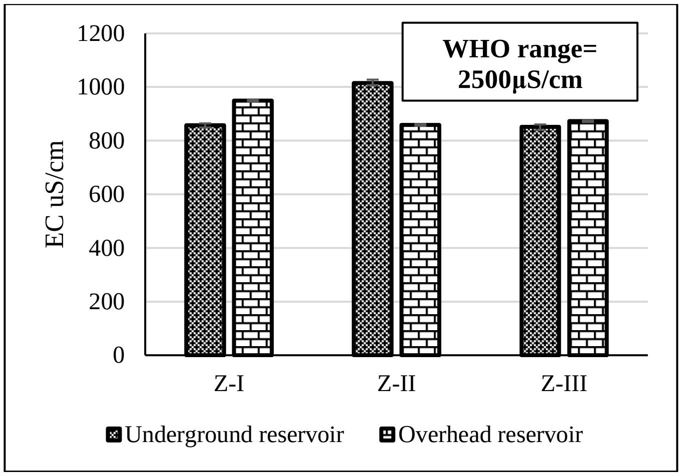

Fig 3: Variation in EC values of underground and overhead water storage reservoirs

Turbidity: Number of suspended particles present in water samples is known as its turbidity [29]. The turbidity values of both underground and overhead storage reservoirs ranged between 0.88-1.97 NTU and 1.24-2.2 NTU respectively. The highest value of turbidity was observed in sample obtained from overhead reservoir of Z-I which is 2.2 NTU while lowest value of turbidity was recorded in sample obtained from underground reservoir of Z-I which is 0.88 NTU. But the turbidity of all the samples obtained from underground and overhead reservoirs was found to be within the limits set by WHO and PDWQS that is 5 NTU as shown in the Fig 4. Similar study was conducted by Duressa and coworkers in 2019 in which physico chemical and microbial drinking water quality monitoring of samples from source to household tap was performed. The values of turbidity ranged between 0-12 NTU which is within the limit set by WHO for some samples and exceeds the limit set by WHO for other samples [30].

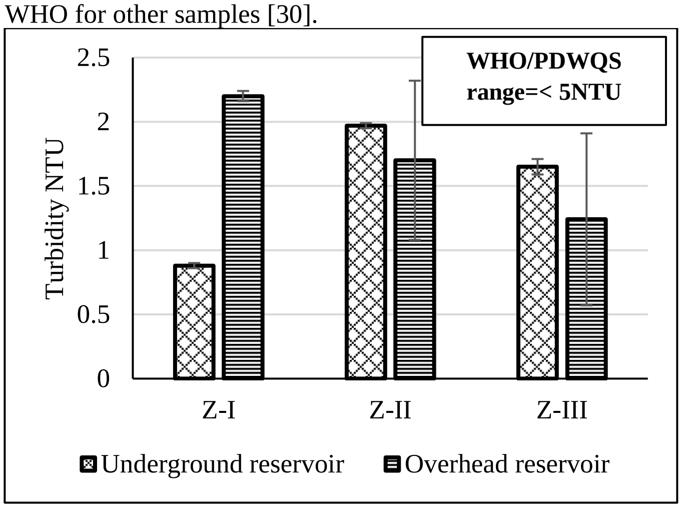

Fig 4: Variation in Turbidity values of underground and overhead water storage reservoirs

Dissolved oxygen (DO): Dissolved oxygen (DO) assesses the waste assimilative capacity of the waters [31]. The DO values of raw water in all the sampling sites ranged from 9.05-9.2 mg/L and the value of DO for the overhead reservoirs ranged from 9.05-9.1 mg/L, respectively. As in February the temperature was lower due to which value of DO was higher in most of the samples. DO and temperature correlate inversely that is with the increase in temperature the value of DO decreases and vice versa [32]. The highest value of DO was recorded in sample obtained from underground reservoir of Z-II which is 9.2 mg/L while the lowest value of DO was observed in underground reservoir of Z-I and overhead reservoir of Z-II. The values of DO in the current study are higher compared to the limits set by WHO/PDWQS which is 6.5-8.5 mg/L as shown in Fig 5. Kamal and Hashmi in 2021 evaluated the water quality of a residential university and average DO value of all the samples was found above the limit set by WHO/PDWQS [32].

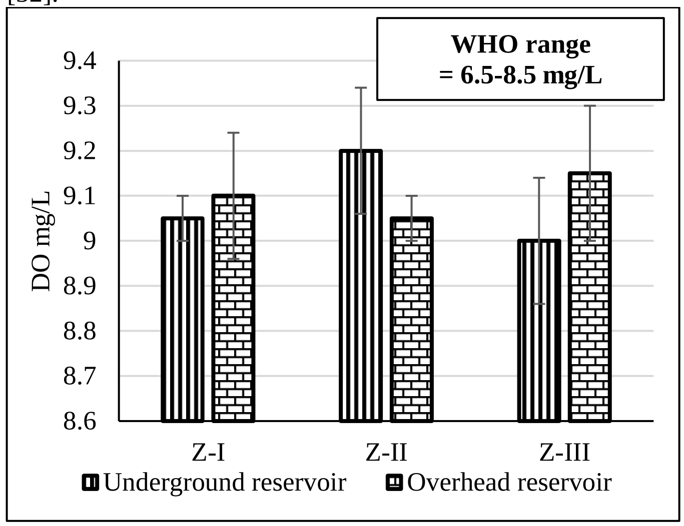

Fig 5: Variation in DO values of underground and overhead water storage reservoirs

Hardness: The quantity of both magnesium and calcium salts in water determines its hardness [27]. The hardness of samples obtained from the underground storage reservoirs ranged between 378-383 mg/L and hardness of samples obtained from the overhead reservoirs ranged between 340-401 mg/L. The highest value of the hardness was observed in overhead storage reservoir of Z-I while lowest value of hardness was observed in overhead storage reservoir of Z-II. The values of hardness for all the samples obtained from selected sampling stations were found within the limit prescribed by WHO/PDWQS which is 500 mg/L as shown in the Fig 6. Similar study was conducted by Werkneh and coworkers in 2015 in which physico-chemical assessment of drinking water of Jigjiga city Ethopia was carried out and the highest value of hardness was 362 mg/L which is also within the limit set by WHO/PDWQS similar to our results [33].

Alkalinity: Total alkalinity of water is defined as the water containing carbonate, hydroxide, and bicarbonate compounds of sodium, calcium, and potassium [32]. The values of alkalinity for underground reservoirs ranged between 402-405 mg/L while values of alkalinity for overhead reservoirs ranged between 342-435 mg/L. The maximum value of alkalinity was found in sample obtained from overhead reservoir of Z-I which is 435 mg/L while lowest value of alkalinity was found in samples obtained from underground and overhead water storage reservoir of Z-III which is 402 mg/L. The values of alkalinity of all samples were found within the prescribed limit of WHO/PDWQS which is 500 mg/L as shown in Fig 7. Similar study was carried out by Sila in 2019. In this study the values of alkalinity for various samples obtained from dams, furrows, rivers, springs, rainwater, borehole ranged between 59-196 mg/L which is within the limit set by WHO/PDWQS similar to our study [34].

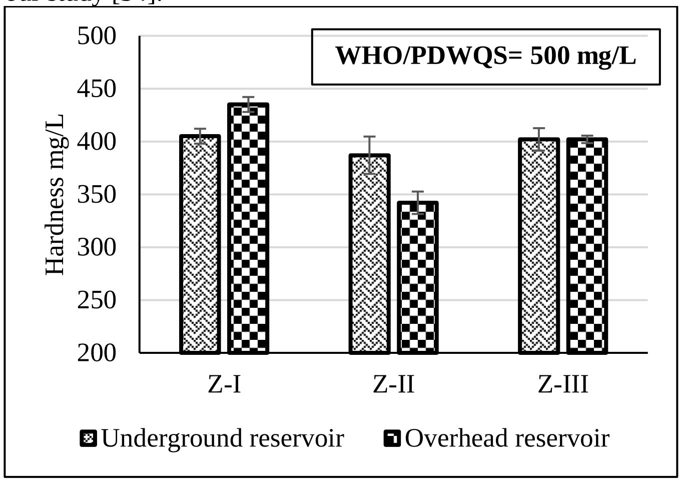

Fig 6: Variation in Hardness values of underground and overhead water storage reservoirs

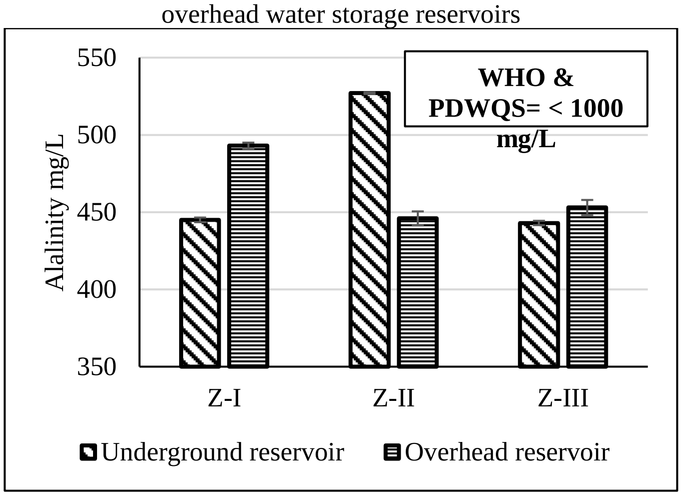

Fig 7: Variation in Alkalinity values of underground and overhead water storage reservoirs

Total suspended solids (TSS): Total suspended solids (TSS) provide the attachment sites for microbes. Hence, it is very important parameter to assess the quality of drinking water. The values of TSS in underground storage reservoirs ranged between 10-20 mg/L while the values of TSS in all samples obtained from overhead reservoirs ranged between 3.3-10 mg/L. The highest value of TSS was recorded in sample obtained from underground storage reservoir of Z-II which is 20 mg/L while lowest value of TSS was found in sample obtained from overhead reservoir of Z-III which is 3.3 mg/L. The maximum value of TSS in sample obtained from underground storage reservoir of Z-II was probably due to the corrosion of storage tank material or due to the rusting of water distribution pipes. TSS of most of the samples was found above the prescribed limit of WHO/PDWQS which is 5 mg/L as shown in the Fig 8. The highest TSS value may provide the more attachment sites to the microbes because of more surface area [32]. Similar study was conducted by Khan and coworkers, 2021 and assessed the TSS values in drinking water sources of district Bajaur, Pakistan. The values of TSS were found above the prescribed limit of WHO/PDWQS [35].

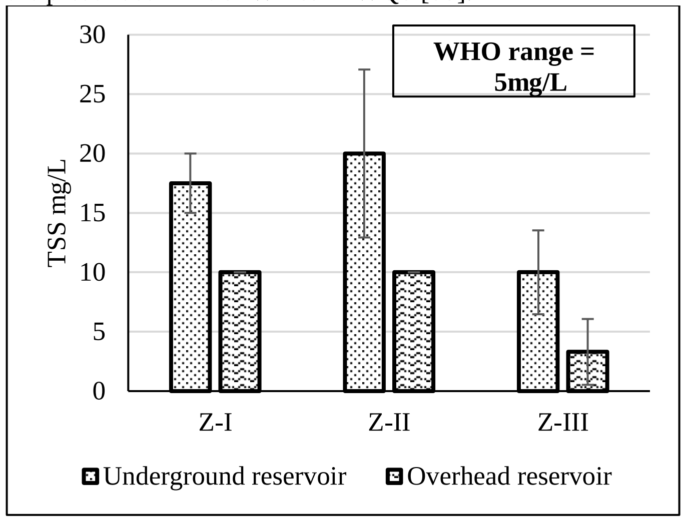

Fig 8: Variation in TSS values of underground and overhead water storage reservoirs

Total dissolved solids (TDS): Water dissolves diverse range of organic and inorganic minerals in it. The high values of TDS in water makes it unfit for drinking purposes. The TDS values of samples obtained from underground storage reservoirs ranged between 443-527 mg/L while the values of TDS of samples obtained from overhead storage reservoirs ranged between 446-493 mg/L. The highest value of TDS was observed in sample obtained from underground storage reservoir of the Z-II which is 527 mg/L while the lowest value of TDS was observed in sample obtained from underground storage reservoir of Z-III which is 443 mg/L. The values of TDS in all the samples obtained from selected sampling stations were found to be within the limit set by WHO/PDWQS which is <1000 mg/L as shown in the Fig 9. Similar study was done by Mullahmattathil and coworkers in 2015 in which analysis of TDS contents of drinking water in Mafikeng, South Africa was performed. The TDS values of all the samples ranges between 159-364 mg/L which is within the limit set by WHO/PDWQS similar to our results [36].

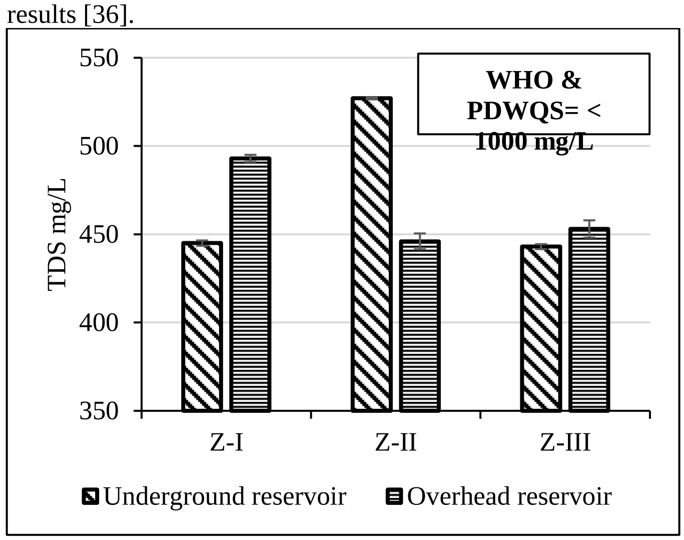

Fig 9: Variation in TDS values of underground and overhead water storage reservoirs

Residual chlorine: Chlorine is a powerful disinfectant that is added to water to remove microbial contamination and make it safe to drink. The amount of residual chlorine at the consumer end will be determined by the amount of chlorine added to the water [37]. The amount of the residual chlorine in underground storage reservoirs ranged between 0.08-0.14 mg/L while the amount of residual chlorine in samples obtained from overhead storage reservoirs ranged between 0.19-0.28 mg/L. The highest amount of residual chlorine was found in the sample obtained from overhead storage reservoir of Z-II which is 0.28 mg/L while lowest amount of residual chlorine was found in sample obtained from underground storage reservoir of Z-III which is 0.08 mg/L. The chlorine was also found in unchlorinated water of underground storage reservoirs as during the sampling period chlorine was used in underground storage reservoirs for cleaning purpose. However, the amount of chlorine in samples of overhead storage reservoirs was higher compared to the samples obtained from underground storage reservoirs but far less than the prescribed limit for efficient disinfectant. Moreover, most of the samples obtained from the selected sampling stations have less amount of chlorine compared to the limit set by WHO/PDWQS which should be 0.5-1.5 mg/L at source and 0.2-0.5 mg/L at consumer end as shown in Fig 10. The amount of chlorine in all the three zones may decrease despite adding 1 ppm dose due to the reason that when chlorine is added to water, some of the chlorine reacts initially with inorganic and natural elements and metals present and is unavailable for disinfection; this portion of the chlorine is known as the water's chlorine demand, and the remaining chlorine is known as total chlorine. Free chlorine and mixed chlorine are subsets of total chlorine. When chorine reacts with molecules containing inorganic nitrogen, such as nitrates, etc., as well as organic nitrogen, such as urea, etc., it serves as a weak disinfectant that is ineffective for disinfection. As a gauge of the water's potability, free chlorine measures the amount of chlorine that is still available to inactivate pathogens [38]. So, the added chlorine may be consumed in this way and hence do not fulfil the requirement for efficient disinfection. Moreover, turbidity also plays an important role in proper disinfection [32]. In the current study the value of turbidity is > 0.5 NTU in most of the samples. Due to higher values of turbidity the high amount of disinfectant is required for proper disinfection [33]. Results of current study are similar to the study conducted by Duressa and coworkers in 2019. In this study residual chlorine values of drinking water Nekemte, Oromia, Ethiopia was examined. Residual chlorine was found less than 0.5 mg/L and 0.2 mg/L at source and consumer end, respectively [30].

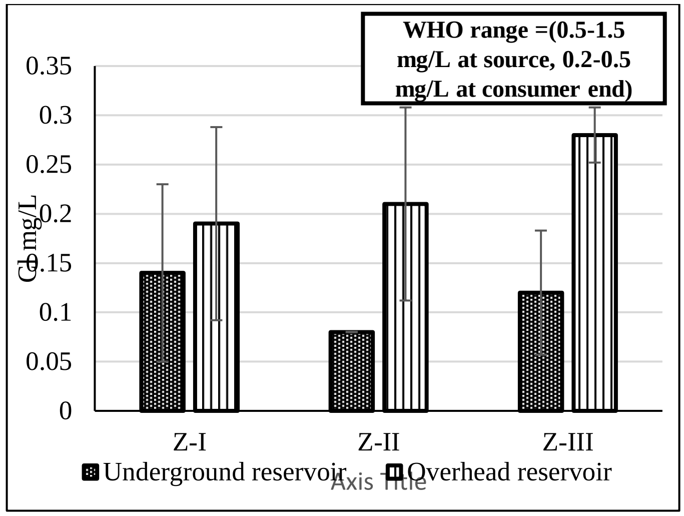

Fig 10: Variation in Residual Chlorine values of underground and overhead water storage reservoirs

Microbial analysis

The presence of fecal and total coliform in all the samples was identified by Most Probable Number Technique (MPN). The value of total and fecal coliform for samples obtained from underground storage reservoir range between 16->23/100 ml while the values of MPN index for samples obtained from overhead reservoirs ranged between 1.1-12/100 ml. The highest value of MPN index was recorded in sample obtained from underground storage reservoir of Z-I which is >23 with 95% probability range of (13-…..) while lowest value of MPN index was observed in sample obtained from overhead storage reservoir of Z-III which is 1.1 with 95% probability range of (0.05-5.1). The lowest value of MPN index for the sample obtained from overhead storage reservoir of Z-III was due to the presence of residual chlorine which is 0.28 mg/L. Water chlorination is mostly used to kill or remove bacterial contaminants in order to make it safe and healthy for drinking purposes. The MPN index of the chlorinated water should drop following chlorination, but the storage reservoir has not received the requisite amount of chlorine addition for effective disinfection. The MPN index for sample obtained from overhead storage reservoir of Z-III has reduced but not properly eliminated as shown in the Table 2. Kamal and Hashmi (2021) assessed the physico-chemical and bacteriological analysis of tap water of a same university of Pakistan. In this particular study results show that the MPN index of all the water samples was found above the limit set by WHO/PDWQS [5].

Table 4: p-values (P(T<=t) two tail) of physico-chemical parameters of all three zones

Sampling sites	pH	DO	EC	Turbidity	Hardness	Alkalinity	TSS	TDS	Residual Chlorine
Z-1	0.66	0.7	0.01	0.2	0.5	0.2	0.2	0.006	0.5
Z-II	0.5	0.2	0.03	0.4	0.1	0.07	0.05	0.03	0.3
Z-III	0.5	0.6	0.4	0.2	0.5	0.5	0.5	0.25	0.23

Table 3: Variation in MPN index of water samples obtained from underground and overhead water storage reservoir

Sample	Zones	MPN Index/100 ml	95% probability range	WHO limit	PDWQS
Underground reservoir	Z-I	>23	13-…..	0/100 ml	0/100 ml
	Z-II	16	5.8-34		
	Z-III	16	5.8-34		
Overhead reservoir	Z-I	3.6	0.91-0.97		
	Z-II	12	4.8-24		
	Z-III	1.1	0.051-5.9		

Statistical Analysis

Statistical analysis was conducted to determine the significant difference between water from underground and overhead reservoirs such as Paired t-test at 0.5 significant level test (at 95% confidence level) was performed by using Microsoft excel 365. Results of paired t-test reveal that '*p'* value for EC (Z-I p= 0.01, Z-II p= 0.003) and TDS (Z-I p= 0.006, Z-II p= 0.03) is significantly less (0.05). Likewise, the critical value is also smaller than measured t-statistics value for all the three locations. This revealed that the difference in samples from underground and overhead reservoirs is significant. P value for all other parameters were greater than 0.05 showing that the difference is insignificant between the water samples of underground and overhead reservoirs as shown in Table 3. This may be due to low detection of chlorine in overhead reservoirs and the water quality may remain unchanged before and after chlorination.

Conclusions

The results of the current study indicate that all the selected physico-chemical parameters of all samples were within the prescribed limit set by WHO/PDWQS except dissolved oxygen (DO), total suspended solids (TSS) and residual chlorine. Water from storage reservoirs of National University is contaminated. TSS of samples obtained from both underground and overhead storage reservoirs was found to exceed the prescribed limit by WHO/PDWQS and hence greater amount of TSS provides more sites for microbial attachment. Microbial analysis of all samples from selected sampling stations through MPN also shows that the water is contaminated and unfit for drinking purposes. Proper dosages of chlorine should be used for efficient disinfection. Moreover, statistical analysis also reveals that there is no significant difference in physico-chemical parameters of samples obtained from underground and overhead reservoirs except EC and TDS having P values <0.05. This may be due to lesser amount of chlorine in samples of overhead storage reservoirs.

Recommendations

According to WHO/PDWQS ground water if used for drinking purpose must have a 0/100 ml of MPN index but in current study all the samples have MPN index greater than 0 and TSS is above the permissible limits of WHO. So, water should be filtered and chlorinated carefully before supplying to overall community. Moreover, it is necessary to prevent water contamination in storage reservoirs by scheduling regular inspections and cleaning of reservoirs. Lack of proper monitoring of centralized water supplies also raise the issue of water contamination and ultimately causing the serious threats to well-being of community.

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References

1. Atanfu, B., Desta, A., & Assefa, F. (2021). Microbial Community Structure and Diversity in Drinking Water Supply, Distribution Systems as Well as Household Point of Use Site in Addis Ababa City, Ethiopia
2. Khan K, Lu Y, Saeed MA, Bilal H, Sher H, Khan H, Ali J, Wang P, Uwizeyimana H, Baninla Y, Li Q, Liu Z, Nawab J, Zhou Y, Su C, Liang R (2018). Prevalent fecal contamination in drinking water resources and potential health risks in Swat, Pakistan. *Journal of Environmental Science 72*, 1–12
3. Daud, M. K., Nafees, M., Ali, S., Rizwan, M., Bajwa, R. A., Shakoor, M. B., Arshad, M.U., Chatha, S.A.S., Deeba, F., Murad, W., Malook, Ijaz., & Zhu, S. J. (2017). Drinking water quality status and contamination in Pakistan. *BioMed Research International*, *2017*.
4. Ekere, N. R., Agbazue, V. E., Ngang, B. U., & Ihedioha, J. N. (2019). Hydrochemistry and water quality index of groundwater resources in Enugu north district, Enugu, Nigeria. *Environmental Monitoring and Assessment*, *191(3)*, 1-15.
5. Kamal,H., & Hashmi,I. (2021). Physicochemical and bacteriological analysis of tap water of a residential university of Pakistan. *International Research Journal of Environmental Sciences. 10(3),* 15-29.
6. Ondieki, J. K., Akunga, D. N., Warutere, P. N., & Kenyanya, O. (2021). Bacteriological and physico-chemical quality of household drinking water in Kisii Town, Kisii County, Kenya. *Heliyon*, *7*(5), e06937.
7. Cooper, R. (2018). Water, sanitation and hygiene services in Pakistan. *Epidemiology,* 23 (1), 107-115.
8. Price, H., Adams, E., & Quilliam, R. S. (2019). The difference a day can make: The temporal dynamics of drinking water access and quality in urban slums. *Science of the Total Environment*, *671*, 818-826.
9. Miller, M., Cronk, R., Klug, T., Kelly, E. R., Behnke, N., & Bartram, J. (2019). External support programs to improve rural drinking water service sustainability: A systematic review. *Science of the Total Environment*, 670, 717-731.
10. Emenike, C. P., Tenebe, I. T., Omole, D. O., Ngene, B. U., Oniemayin, B. I., Maxwell, O., & Onoka, B. I. (2017). Accessing safe drinking water in sub-Saharan Africa: Issues and challenges in South–West Nigeria. *Sustainable Cities and Society*, *30*, 263-272.

11. Eletta, O. A., Adeniyi, A. G., Ighalo, J. O., Onifade, D. V., & Ayandele, F. O. (2020). Valorisation of Cocoa (Theobroma cacao) pod husk as precursors for the production of adsorbents for water treatment. *Environmental Technology Reviews*, *9*(1), 20-36.
12. Anwar, M. S., Lateef, S. H. A. H. L. A., & Siddiqi, G. M. (2010). Bacteriological quality of drinking water in Lahore. *Biomedica*, *26*(1), 66-69.
13. Awan, F., Ali, M. M., Afridi, I. Q., Kalsoom, S., Firyal, S., Nawaz, S., Akhtar, R., Iqbal, A., Saeed, S., Naseer, R., Memood, T., Luqman, N., Ahmed, H.M., Sadia, H., Taseer, M.S.A., Khan, A.R., & Rafique, N. (2022). Drinking water quality of various sources in Peshawar, Mardan, Kohat and Swat districts of Khyber Pakhtunkhwa province, Pakistan. *Brazilian Journal of Biology*, *84*.
14. Mehmood, S., Ahmad, A., Ahmed, A., Khalid, N., & Javed, T. (2013). Drinking water quality in capital city of Pakistan. *Sci Rep*, *2*(2), 1-6.
15. Kioko, K. J., & Obiri, J. F. (2012). Household attitudes and knowledge on drinking water enhance water hazards in peri-urban communities in Western Kenya. *Jàmbá: Journal of Disaster Risk Studies*, *4*(1), 1-5.
16. Saddozai, A. A., Samina, K., & Tabassum, H. (2009). Microbial quality of food snacks and drinking water in Islamabad schools and colleges. *Pakistan Journal of Agricultural Research*, *22*(3/4), 144-149.
17. Shabbir, R., & Ahmad, S. S. (2015). Use of geographic information system and water quality index to assess groundwater quality in Rawalpindi and Islamabad. *Arabian Journal for Science and Engineering*, *40*(7), 2033-2047.
18. Jadoon, W. A., Arshad, M., & Ullah, I. (2012). Spatio-temporal microbial water quality assessment of selected natural streams of Islamabad, Pakistan. *Records Zoological Survey of Pakistan*, *21*, 14-18.
19. Ahmed, T., Imdad, S., & Butt, N. M. (2015). Bacteriological assessment of drinking water of Islamabad Capital Territory, Pakistan. *Desalination and Water Treatment*, *56*(9), 2316-2322.
20. Roy, M., & Shamim, F. (2021). Assessment of water quality for drinking purpose in various educational institute of Tamluk, East Midnapore, West Bengal, India. *Journal of Water Pollution & Purification Research*, *8*(1), 25-31p.
21. APHA, American Public Health Association, "Standard Methods for the Examination of Water and Wastewater", Washington, D.C., 23rd ed, 2017.
22. WHO (2017). Guidelines for drinking water quality: first addendum to the fourth edition. World Health Organization Press, Switzerland. ISBN: 978-92-4-155001-7
23. Drinking water in Pakistan (2008). National Standards for Drinking Water Quality. Pakistan Environmental Protection Agency. http://www.freshwateraction.net/sites/freshwateraction.net/files/Drinking%20water%20in%20Pakistan.pdf.(June/2008).
24. Omezuruike, O. I., Damilola, A. O., Adeola, O. T., Fajobi, E. A., & Shittu, O. B. (2008). Microbiological and physicochemical analysis of different water samples used for domestic purposes in Abeokuta and Ojota, Lagos State, Nigeria. *African Journal of Biotechnology*, *7*(5), 617-621.
25. Ali, S. S., Anwar, Z., & Khattak, J. Z. K. (2012). Microbial analysis of drinking water and water distribution system in new urban Peshawar. *Current Research Journal of Biological Sciences*, *4*(6), 731-737.
26. Rahmanian, N., Ali, S. H. B., Homayoonfard, M., Ali, N. J., Rehan, M., Sadef, Y., & Nizami, A. S. (2015). Analysis of physiochemical parameters to evaluate the drinking water quality in the State of Perak, Malaysia. *Journal of Chemistry*, *2015*.
27. Sailaja, V., & Umamaheswari, P. (2015). DK kanderi, PK Reddy, and G. Rajoji,"Physicochemical and microbilogical analysis of municipality drinking water,". *International Journal of Current Research*, *7*(8), 19368-19372.
28. Sohaila, M. T., Mahfoozb, Y., Aftabc, R., Yend, Y., Talibe, M. A., & Rasoolf, A. (2020). Water quality and health risk of public drinking water sources: a study of filtration plants installed in Rawalpindi and Islamabad, Pakistan. *Desalination Water Treat*, *181*, 239-50.
29. Meride, Y., & Ayenew, B. (2016). Drinking water quality assessment and its effects on residents health in Wondo genet campus, Ethiopia. *Environmental Systems Research*, *5*(1), 1-7.
30. Duressa, G., Assefa, F., & Jida, M. (2019). Assessment of bacteriological and physicochemical quality of drinking water from source to household tap connection in Nekemte, Oromia, Ethiopia. *Journal of Environmental and Public Health*, *2019*.
31. Rao, G. S., & Nageswararao, G. (2010). Study of groundwater quality in Greater Visakhapatnam City, Andhra Pradesh (India). *Journal of Environmental Science & Engineering*, *52*(2), 137-146.
32. Kamal, H., & Hashmi, I. (2021). Water quality assessment of raw and chlorinated drinking water of a residential university. *NUST Journal of Engineering Sciences*, *14*(1), 12-19.
33. Werkneh, A. A., Medhanit, B. Z., Abay, A. K., & Damte, J. Y. (2015). Physico-chemical analysis of drinking water quality at Jigjiga City, Ethiopia. *American Journal of Environmental Protection*, *4*(1), 29-32.
34. Sila, O. N. A. (2019). Physico-chemical and bacteriological quality of water sources in rural settings, a case study of Kenya, Africa. *Scientific African*, *2*, e00018.
35. Khan, M. H., Nafees, M., Muhammad, N., Ullah, U., Hussain, R., & Bilal, M. (2021). Assessment of drinking water sources for water quality, human health risks, and pollution sources: a case study of the District Bajaur, Pakistan. *Archives of Environmental Contamination and Toxicology*, *80*(1), 41-54.
36. Mulamattathil, S. G., Bezuidenhout, C., & Mbewe, M. (2015). Analysis of physico-chemical and bacteriological quality of drinking water in Mafikeng, South Africa. *Journal of Water and Health*, *13*(4), 1143-1152.

37. M. J. Brandt and Ratnayaka, "Pumping, electrical plant and control and instrumentation", *Twort's Water Supply, 7 ed*., 2017.
38. Mazhar, M. A., Khan, N. A., Ahmed, S., Khan, A. H., Hussain, A., Changani, F., Yousefi, M.,Ahmadi, S., & Vambol, V. (2020). Chlorination disinfection by-products in municipal drinking water–a review. *Journal of Cleaner Production*, *273*, 123159

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