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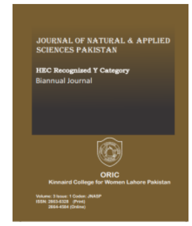

A SYSTEMATIC APPROACH FOR SUSTAINABLE DRINKING WATER QUALITY ASSESSMENT USING BASIC TECHNIQUES IN ISLAMABAD, PAKISTAN

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Abstract

This study investigates the water quality of filtration facilities in Defense Housing Authority Phase II, Islamabad, Pakistan, by examining 22 samples for physicochemical and microbiological contamination. Evaluation parameters include pH, EC, TDS, TS, sulfate, chloride, and total hardness, measured before, during, and after filtration. Results indicate that pH, EC, chlorides, and sulfates fall within acceptable ranges according to PSQCA standards. However, TDS, TS, and total hardness exceed acceptable limits in certain samples. The findings underscore the importance of monitoring and optimizing water treatment processes to ensure consistent adherence to water quality standards for public health and safety.

1. Introduction

Ensuring proper utilization of potable water is vital for sustaining health and preserving the natural ecosystem. Water, a substance devoid of taste and odor, serves as the predominant element in the composition of the Earth, encompassing its rivers, lakes, and oceans. Physiochemical factors, due to their direct influence on microbial growth, significantly contribute to determining water quality. Out of the total water content, 97% constitutes seawater, 3% is freshwater, 2% remains frozen in glaciers and polar ice caps, and a mere 1% is designated for drinkable purposes (Kataria *et al.*, 1996). In Pakistan, the availability of safe drinking water is insufficient, as only a quarter of the population enjoys sustained access to it. The prevalence of waterborne diseases in the country is mainly attributed to the contamination of drinking water by municipal sewage and industrial waste (Hashmi *et al.,* 2009). Water must be devoid of preservatives, color, turbidity, odor, and, crucially, bacteria that compromise its quality. When sourced from surface reservoirs, it is imperative to render water safe for human consumption. Consequently, chlorination stands out as the indispensable method for purifying water by disinfecting pathogens (Chilton *et al.,* 2001). Several features are considered crucial for ensuring the quality of drinking water, leading the Environmental Protection Agency (EPA) to establish two distinct categories of drinking water standards: primary and secondary. Primary standards focus on regulations related to organic and inorganic contaminants, microbial pathogens, and radioactive substances that could endanger drinking water safety. Conversely, secondary standards address parameters such as chlorides, copper, manganese, sulfates, zinc, iron, pH, total dissolved solids, corrosivity, foaming agents, color, and odor. These elements primarily affect the taste, odor, color, and overall appearance of water. The designation "SMCL" signifies the maximum allowable concentration of these pollutants in the water supply (Treacy, 2019). According to Daud *et al*., (2017) approximately 20% of Pakistan's overall population has access to safe drinking water. The remaining 80% of the populace is compelled to use unsafe drinking water due to a scarcity of secure and healthy water sources. Global rankings on drinking water quality position Pakistan as 80th worldwide and 11th in Asia (Daud *et al*., 2017). Human activities contribute to waterborne diseases, constituting around 80% of all illnesses and contributing to 33% of total fatalities. This review emphasizes the quality of drinking water, sources of contamination, sanitation conditions, and the impact of unsafe drinking water on human health. Urgent measures and treatment technologies are essential to address the unhygienic state of drinking water supplies in various regions of Pakistan (Soomro *et al*., 2011). The decline in water quality is attributed to substantial contamination. Projections indicate that the population is expected to increase from 141 million to 221 million by

2025, while per capita water availability is projected to decrease from 5,600m3 to 1,000m3. The degradation of water quality is a consequence of unregulated discharge of untreated domestic and industrial wastewater into natural water bodies (Farooqi *et al*., 2007). The World Health Organization defines "safe-drinking water" as water posing no significant health risks during consumption. In developing countries, 80% of human infections stem from biological contamination of water. The quality of drinking water faces challenges due to escalating human consumption and the adverse effects of growing urbanization and industrialization (Nabeela *et al*., 2014). Haydar *et al.,* (2009) conducted a case study to evaluate the water quality of WASA filtration plants in Punjab areas. The physiochemical and biological parameters at each source (T/W) in the respective areas were found to be within acceptable ranges, indicating suitability for drinking supply purposes. However, a recent study by Ahmed et al., (2007) in the Hayatabad area of Peshawar, Pakistan, concluded that the chemical quality of drinking water samples did not meet WHO standards, rendering it unfit for drinking and other purposes. Mohsin *et al*., (2013) reported high concentrations of calcium in the satellite town area of Lahore, Pakistan, exceeding permissible limits set by PAK-EPA. Additionally, chloride concentrations in Islamic colony exceeded permissible limits, while sodium levels in Shahdrah were below WHO standards but still potentially harmful to local inhabitants. Other parameters also showed significant deviations from WHO standards (Ahmed et al., 2023). The significant aspect behind the assessment of drinking filtration plants in Pakistan is crucial for safeguarding public health and protecting the environment. It ensures compliance with water quality standards, raises community awareness, and informs policy decisions (Ahmed et al., 2023). Additionally, research on filtration plant performance drives advancements in water treatment technologies and practices, addressing emerging contaminants and challenges in water quality management. Therefore, this research emphasizes the pressing need for comprehensive and continuous monitoring of water quality parameters within filtration facilities, as well as the proactive optimization of treatment processes to consistently uphold established water quality standards (Ahmed *et al*., 2023). To anticipate evolving water quality patterns in the next 10 to 50 years, an analysis of scenarios was undertaken. The examination specifically concentrated on regions experiencing a decline in water quality, emphasizing those with significant implications for social, economic, or ecological factors influencing the changes in water quality (Meybeck *et al*., 1990). The declining quality of drinking water in Pakistan is a growing concern, exacerbated by the rapid population growth and extensive development. This research delivers insights into the current status of drinking water quality across various sectors in Defense Housing Scheme Phase II, Islamabad, Pakistan. The assessment encompasses the physicochemical attributes of drinking water and the detection of harmful bacteria (Daud et al., 2017). The research aims to evaluate physicochemical parameters (pH, TDS, TS, Total Hardness, Cl-, EC, SO42-) and investigate microbiological contamination. Additionally, the study focuses on assessing the efficiency of filtration facilities (Daud *et al.*, 2017). Study Area Defense Housing Authority Phase II comprises several sectors, with each sector serving as a distinct research area for the collection of water samples from different filtration units. Geographically situated near the southeastern edge of Islamabad, the study involved the collection of water samples from filtration plants and tube wells located in various sectors. The latitude and longitude coordinates of each filtration plant and tube well were recorded. Refer to Fig. 1 for the map of the study area.

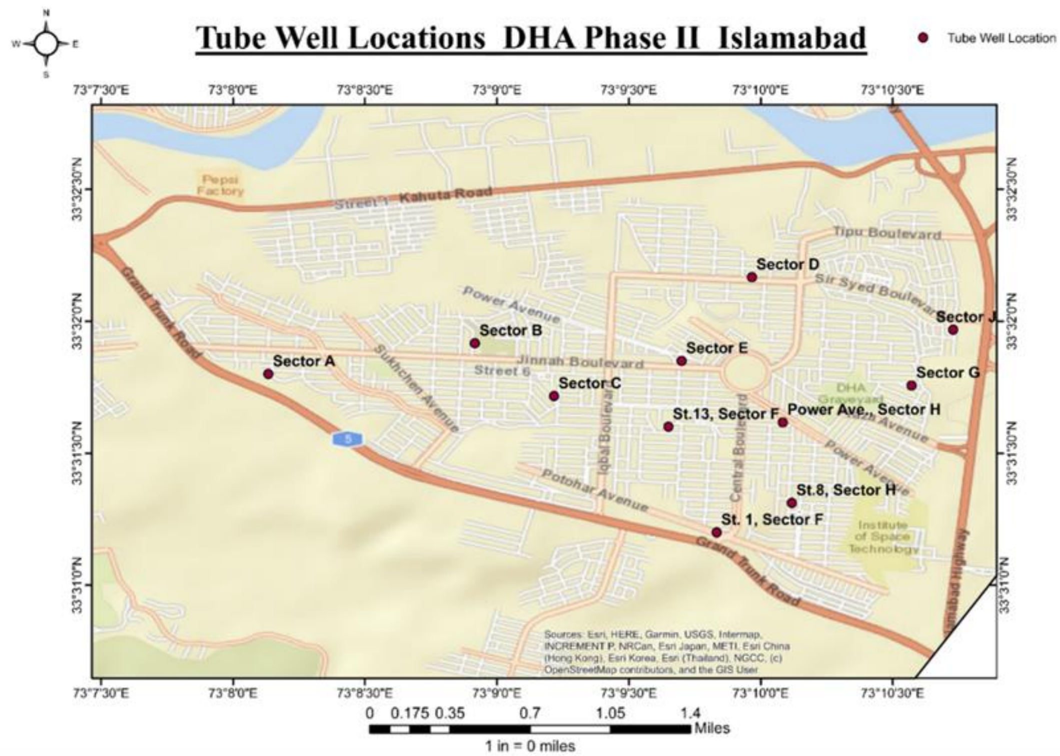

Fig.1 Map showing the tube wells locations from the study area.

2.Material and Methods

2.1 Sample Analysis

For the analysis of different parameters in water samples, three distinct types of bottles were utilized. Polyethylene bottles, as described by (Daud *et al.*, 2017), were employed for assessing physical and chemical parameters. Sterilized glass bottles, on the other hand, were utilized for analyzing microbiological contamination.

2.2 Samples Preservation

A total of 22 water samples were collected from different sectors (A, B, C, D, E, F, G, H, and J) of Defense Housing Authority Phase II in Islamabad. The majority of the filtration facilities were found to be in good operational condition. The sampling took place in August 2021, with the bottles initially cleaned using distilled water. Subsequently, the bottles were thoroughly washed with the source water before the final sample collection. After collecting the samples, the bottles were securely sealed, placed in an icebox, and transported back to the EPA lab for subsequent analysis (Ahmed *et al*., 2023). The pH, Total Dissolved Solids, and Electrical Conductivity were each tested on the spot with portable equipment. In the labs, other parameters were examined. Using Merck's "water check kit," a qualitative examination of coliform and E. coli bacteria contamination was performed. Human faeces will identify E. coli, an indicator that the water quality is poor. The set includes a sterile container as well as a blister pack. By opening the container's top, 50 ml of the water sample is put into it until the red line is reached (Ahmed *et al*.,2023).

Table 1: General characteristics of filtration plants and their sources

SampleID	Sectors (DHA-II)	Height Of tank (ft)	Source	Location	
				Latitude	Longitude
F1	G	100	Tubewell	33˚31’45.40”N	73˚10’34.31’’E
F2	J	90	Tubewell	33˚31’58.08”N	73˚10’43.75’’E
F3	D	116	Tubewell	33˚32’10.02”N	73°9’58”E
F4	E	100	Tubewell	33˚31’51”N	73°9’42.01”E
F5	B	100	Tubewell	33˚31’55”N	73°8’55”E
F6	A	110	Tubewell	33˚31’48.02”N	73°8’8.02”E
F7	C	100	Tubewell	33˚31’43”N	73°9’13”E
F8	St.13 ,F	100	Tubewell	33˚31’36.02”N	73°9’39”E
F9	St.1, F	100	Tubewell	31˚31’12”N	73°9’50”E
F10	PowerAve., H	100	Tubewell	33˚31’37.02”N	73˚10’5.02”E
F11	St.8, H	100	Tubewell	33˚31’18.70”N	73˚10’7.07”E

2.3 Sampling Technique

The study employed three different types of bottles for analyzing various parameters in water samples. Polyethylene bottles were used for assessing physical and chemical characteristics, while glass bottles were utilized for microbiological contamination analysis. A portable pH meter was employed for immediate determination of pH after sample collection, calibrated before usage (Ahmed *et al*., 2023). The pH probe was immersed in a 250 ml beaker containing the sample, and after stabilizing readings, values were recorded through three repetitions for each sample. Total dissolved solids (TDS), representing inorganic salts and trace organic matter, were assessed using a conductivity probe converting conductivity data into TDS values. The specialized conductivity measurements were conducted with LOVIBOND Senso Direct

150 (Ahmed *et al.*, 2023). TDS was determined by placing 20 ml of sample water in a beaker, immersing the electrodes, and reading the results on the meter screen. The total hardness in the samples was evaluated through titration against a standard solution of EDTA, using EBT as the indicator. The computation of total hardness in the samples was performed according to a specified formula.Total hardness = titration value * 1000 / volume of sample …. (1) The electrical conductivity (EC) of the samples was gauged using a meter from the LOVIBOND Company. The determination of sulfate in the samples was conducted through the UV-visible spectrometry method. Qualitative analysis of microbial contamination involving coliform and E. coli bacteria was performed using the Merck "water check kit."

3. Results and Discussion

This research includes the determination of various properties of water in filtration plants by testing three different parameters. The tested parameters were physical (pH, TDS, EC), chemical (Total Hardness, Ca2+, Mg2+, Cl1-, and SO42-), and biological (E. coli).

3.1 Physical Parameters

3.1.1 pH

Samples were obtained from a total of 11 filtration plants across various sectors of Defense Housing Authority Phase 2, Islamabad. The pH analysis was conducted using the LAQUA act pH120 instrument by HORIBA. Prior to treatment, the pH ranged from 7.25 to 8.38 with a mean value of 7.7. Post-treatment, the pH range shifted to 6.72-8.35, with a mean value of 7.6. The pH levels of water samples from filtration plants, both before and after treatment, fell within the acceptable range defined by PAK-EPA (6.5 to 8.5), as depicted in Fig. 2(a). A lower pH value indicates a more corrosive nature of water (Patil & Ahmed, 2011).

3.1.2 TDS

To determine the Total Dissolved Solids (TDS) concentration, the Senso Direct 150 instrument by LOVIBOND was utilized, employing the same sampling method for water collection from filtration plants in various sectors of Defense Housing Authority Phase 2, Islamabad (Ahmed et al., 2023). Analysis of water samples before treatment showed a concentration range of 340 to 545 mg/l, with a mean value of 401.8 mg/l for TDS. Conversely, post-treatment samples from filtration plants indicated a concentration range of 351-568 mg/l, with a mean value of 411.7 mg/l for TDS. Overall, TDS levels in both pre-filtration and post-filtration water samples remained within the limits set by PAK-EPA. However, samples from F1 and F2 exceeded the specified limit, as depicted in Fig. 2(b). Elevated TDS levels in water are associated with health risks, including the development of acute myocardial infarction (heart attack) and ischemic heart diseases (Appavu *et al.*, 2016).

3.1.3 EC

The measured Electrical Conductivity (EC) of water samples collected from filtration plants before treatment varied between 461 and 678 micro-siemens per centimeter (μS/cm), with a mean value of 522.5(μS/cm), analyzed using the

Senso Direct 150 instrument by LOVIBOND. Post-treatment, the samples exhibited EC values ranging from 472 to 711 (µS/cm) with a mean value of 536 (µS/cm), as illustrated in Figure 3. These values were within the permissible limit set by PAK-EPA, which is 1000 (µS/cm), as shown in Fig. 2(c). It's important to note that increased electrical conductivity in water does not have a direct effect on human health (Soylak *et al.*, 2002).

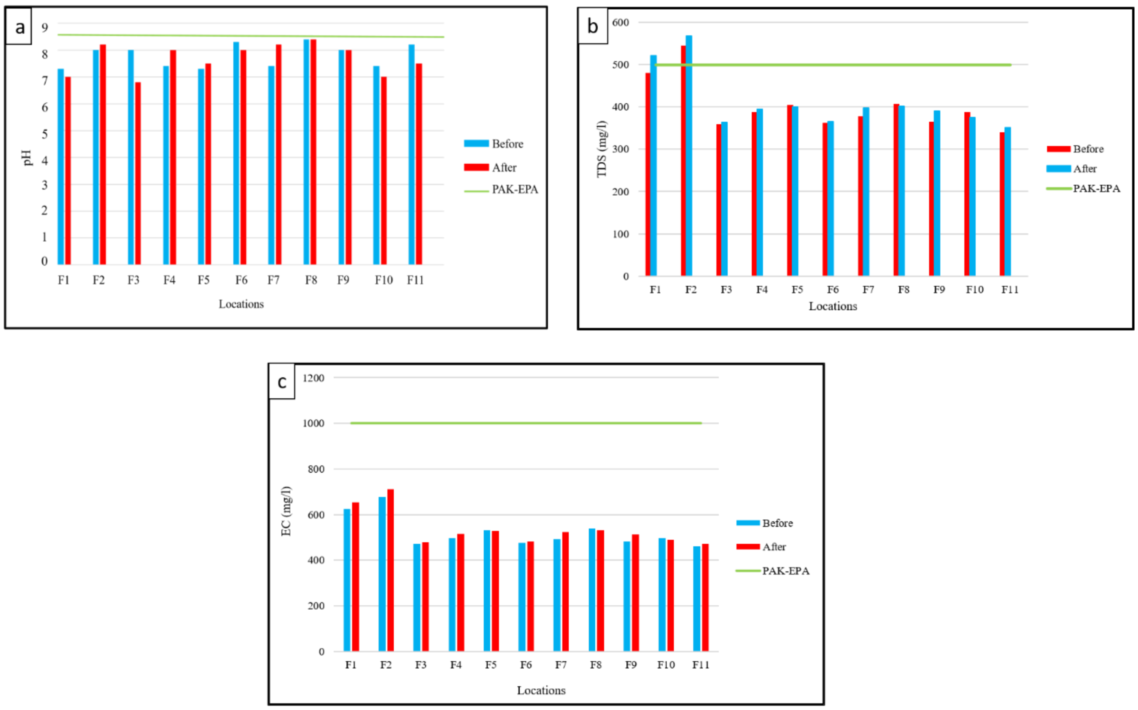

Fig:2 Physical parameters (a) pH, (b) TDS, (c) EC concentrations in the water samples of different sectors of study area.

Table 2. Physical parameters of drinking water samples before and after filtration.

Sectors	Before			After		
		Concentration (mg/l)	Concentration (µS/cm)		Concentration (mg/l)	Concentration (µS/cm)
	pH	TDS	EC	pH	TDS	EC
F1	7.3	481	625	7	494	654
F2	8	545	678	8.2	518	711
F3	8.2	359	471	6.8	364	479
F4	7.4	388	497	8	394	515
F5	7.3	405	531	7.5	401	528
F6	8.3	363	477	8	365	481
F7	7.4	678	492	8.2	397	523
F8	8.4	408	538	8.4	402	531

F9	8	365	482	8	391	513
F10	7.4	388	496	7	375	489
F11	8.2	340	461	7.5	351	472
PAK-EPA	6.5-8.5	100-500	1000	6.5-8.5	100-500	1000

4. Chemical parameters

4.1 Total Hardness

For the chemical analysis of water samples, the total hardness was initially determined using the titration method. Samples from the water supply leading to the filtration plant exhibited a range of total hardness concentrations between 125 and 287 mg/l, with an average value of 229.8 mg/l. Similarly, samples collected after the filtration process showed total hardness concentrations ranging from 124 to 311 mg/l, with an average value of 223.5 mg/l. The total hardness levels in the water samples obtained before and after treatment remained within the acceptable limits established by PAK-EPA, except for F1, F2, and F5, as illustrated in Fig. 3(a).

4.2 Calcium

The analysis of calcium concentrations in the collected water samples yielded varied results. Before treatment, the calcium analysis indicated concentrations ranging from 47 to 94 mg/l, with a mean value of 69.9 mg/l, in the water supply leading to the filtration plants. Similarly, samples collected after filtration showed concentrations ranging from 36 to 128 mg/l, with a mean value of 72 mg/l, as illustrated in Fig. 3(b). The obtained calcium concentrations were then compared to the PAK-EPA standard limit of 200 mg/l, remaining under this limit. Calcium plays a crucial role in supporting human bone health and physiological functions. The majority of calcium is stored in the skeletal system, comprising bones and teeth. Insufficient calcium levels in the human body can lead to conditions like rickets, impaired blood clotting, and increased vulnerability to bone fractures. Conversely, excessive calcium intake can contribute to the development of cardiovascular diseases (Edition, 2011).

4.3 Magnesium

Following established protocols, magnesium analysis was conducted on the collected water samples. The results of the analysis before treatment revealed concentrations ranging from 9.12 to 26.5 mg/l in the water supply. In contrast, water samples collected after filtration exhibited concentrations ranging from 11.8 to 29.7 mg/l, with an average value of 18 mg/l. A comparison was then made between the resulting concentrations of magnesium analysis and the PAK-EPA standard limit of 100 mg/l, as illustrated in Fig. 3(c). Approximately 25g of magnesium is present in the human body, with 60% found in bones and the remaining 40% in tissues and muscles. Magnesium is crucial for the proper functioning of living organisms, including membrane functions and DNA replication. It is essential for the proper functioning of living organisms and is found in minerals like dolomite and magnetite (Soylak et al., 2002).

4.4 Chloride

The collected water samples were also subjected to chloride content analysis using the titration method. The analysis revealed that chloride concentrations ranged from 11.74 to 85.26 mg/l, with a mean value of 35 mg/l, in the water samples before filtration. Similarly, chloride concentrations in the water samples collected after filtration ranged from 11.15 to 88.52 mg/l, with a mean value of 34.86 mg/l. The resulting chloride concentrations remained within the standard limit of PAK-EPA, which is 250 mg/l for chloride, as shown in Fig. 3(d). High chloride concentrations can damage metallic pipes and structures, as well as harm growing plants (Soylak *et al*., 2002).

4.5 Sulfate

Sulfate analysis was conducted on the collected water samples using a UV-visible spectrometer. The results of sulfate analysis before filtration demonstrated varied concentrations ranging from 7.36 to 16.8 mg/l, with an average value of 12.69 mg/l. Similarly, water samples collected after filtration exhibited sulfate concentrations ranging from 7.99 to 19.21 mg/l, with a mean value of 12.22 mg/l. The sulfate concentrations were compared with the PAK-EPA standard limit of 400 mg/l, and the results showed that the sulfate concentrations were within this standard limit, as shown in Fig. 3(e). Elevated sulfate concentrations in water may result from the oxidation of pyrite and mine drainage (Organization, 1984).

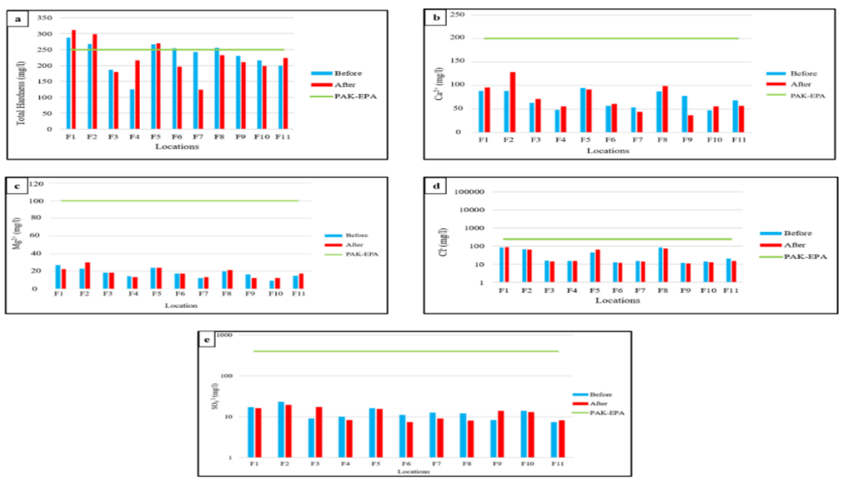

Fig:3 Chemical parameters (a) Total hardness (b) Calcium (c) Magnesium (d) Chloride and (e) Sulfate concentrations in the water samples of study area

Table:3 Chemical parameters of drinking water samples before and after filtration.

Sectors	Before Concentration(mg/l)					After Concentration(mg/l)				
	Total Hardness	Ca	Mg	Cl^-	SO_4^{2-}	Total Hardness	Ca	Mg	Cl^-	SO_4^{2-}
F1	287	88	26	85	17	311	96	22	89	16

F2	267	88	23	67	23	298	128	30	65	19
F3	168	63	18	16	9	180	71	18	14	17
F4	125	48	14	15	10	216	55	13	15	8
F5	266	94	24	44	16	270	91	24	64	15
F6	254	56	17	13	11	196	61	16	12	7
F7	242	53	12	15	12	124	44	13	14	9
F8	255	87	20	83	12	232	99	21	72	7
F9	230	77	16	12	8.	210	36	12	11	13
F10	216	47	9	14	14	168	55	12	13	13
F11	200	68	15	20	7	224	56	17	15	8
PAK-EPA	250	200	100	250	400	250	200	100	250	400

5.Biological Parameters

5.1 E. coli

Water samples were gathered from various sectors of DHA Phase II for the analysis of E. coli bacteria using Merck's "water check" kits. Before filtration, the presence of E. coli was identified in water samples from Sector G, Sector J, Sector A, Sector F st. 13, and Sector H st. 08. Similarly, after the filtration process, E. coli was detected in water samples from Sectors G, E, F st. 13, H POWER AVENUE, and H st. 08 (Ahmed et al., 2023). Significantly, filtration plants in Sector G, Sector F st. 13, and Sector H st. 08 were found to be contaminated with microorganisms due to infrequent replacement of filter paper every six months. Consequently, these plants were unable to efficiently filter out E. coli, leading to a higher count of bacterial colonies, likely originating from sewage infiltration into the water (Ahmed et al., 2023).

Table: 4 Microbial contaminations in drinking water samples before and after filtration.

SampleID	Sectors (DHA-II)	E.coli	
		Before	After
F1	G	positive	positive
F2	J	positive	negative
F3	D	negative	negative
F4	E	negative	positive
F5	B	negative	negative
F6	A	positive	negative
F7	C	negative	negative
F8	F,St.13	positive	positive
F9	F,st1	positive	negative
F10	H, PowerAve	negative	positive
F11	H, st8	positive	positive

6. Conclusion

In conclusion, with the exception of total dissolved salts in samples collected from the F1 and F2 filtration sites, all recorded values of water quality parameters, such as pH, EC, Ca, Mg, Cl-, and SO42-, were found to be within the stipulated limits of PAK-EPA. Total hardness concentrations, however, surpassed the PAK-EPA limit in water samples from the F1, F2, F5, F6, and F8 filtration plants. According to a biological study, samples obtained from the DHA 2 filtration plants in Islamabad were found to contain E. coli. The results indicated that certain samples were unfit for drinking due to contamination with E. coli bacteria. An unexpected discovery was the presence of E. coli in the F4 and F10 filtration plants after treatment but not before treatment, clearly indicating water contamination during the treatment process. Filtration plants should utilize high-quality filter paper and regularly replace their membranes. Swift replacement of Pb-galvanized pipes and fittings is essential. In summary, the assessment of drinking filtration plants using physiochemical and biological measures in DHA Phase II Islamabad, Pakistan, is significant for protecting public health, preserving the environment, ensuring regulatory compliance, empowering communities, informing policy decisions, and driving research and innovation in the field of water quality management.

References

Ahmed, A., Iftikhar, H. and Chaudhry, G. (2007). Water resources and conservation strategy of Pakistan. The Pakistan development review, 997-1009.

Ahmed, T., Ahmad, M. N., Sarwar, B. A., Sultana, R., Nayab, T., Tarique, M., Huda, N. U., Majid, A., & Ullah, S. (2023). Pre & post drinking water quality assessment from the filtration plants of various sectors in dha phase-ii, islamabad, pakistan. Fuuast *Journal of Biology*, 13(2), 75-86.

Appavu, A., Thangavelu, S., Muthukannan, S., Jesudoss, J. S., & Pandi, B. (2016). Study of water quality parameters of cauvery river water in Erode region. *Journal of Global Biosciences*, 5(9), 4556-4567.

Chilton, P., Jamieson, D., Abid, M., Milne, C., Ince, M., & Aziz, J. (2001). Pakistan water quality mapping and management project. Scooping study-draft final report. Loughborough, UK, Water Engineering development Centre, Loughborough University & London school of Hygiene and Tropical Medicines.

Daud, M., Nafees, M., Ali, S., Rizwan, M., Bajwa, R. A., Shakoor, M. B., Arshad, M. U., Chatha, S. A. S., Deeba, F., & Murad, W. (2017). Drinking water quality status and contamination in Pakistan. BioMed research international, 2017.

Edition, F. (2011). Guidelines for drinking-water quality. WHO chronicle, 38(4), 104-108.

Farooqi, A., Masuda, H., & Firdous, N. (2007). Toxic fluoride and arsenic contaminated groundwater in the Lahore and Kasur districts, Punjab, Pakistan and possible contaminant sources. Environmental pollution, 145(3), 839-849.

Hashmi, I., Farooq, S., & Qaiser, S. (2009). Chlorination and water quality monitoring within a public drinking water supply in Rawalpindi Cantt (Westridge and Tench) area, Pakistan. Environmental monitoring and assessment, 158, 393-403.

Kataria, H., Iqbal, S., & Shandilya, A. (1996). Assessment of water quality of Kolar reservoir in Bhopal (MP). Pollution research, 15, 191-193.

Meybeck, M., Chapman, D. V., Helmer, R., System, G. E. M., Organization, W. H., & Programme, U. N. E. (1990). Global Freshwater Quality: A First Assessment. World Health Organization and the United Nations Environment Programme by BlackwellReference.https://books.google. com.pk/books? id=CnagQgAACAAJ

Mohsin, M., Safdar, S., Asghar, F. and Jamal, F. (2013). Assessment of drinking water quality and its impact on resident's health in Bahawalpur city. *International Journal of Humanities and Social Science*, 3(15), 114-128.

Nabeela, F., Azizullah, A., Bibi, R., Uzma, S., Murad, W., Shakir, S. K., Ullah, W., Qasim, M., & Häder, D.-P. (2014). Microbial contamination of drinking water in Pakistan—a review. Environmental Science and Pollution Research, 21, 13929-13942.

Organization, W. H. (1984). Drinking-water Quality. Weekly Epidemiological Record= Relevé épidémiologique hebdomadaire, 59(33).

Patil, G., & Ahmed, I. (2011). Heavy metals contamination assesment of Kanhargaon Dam water near Chhindwara city. Acta Chimica and Pharmaceutica Indica, 1(1), 7-9.

Soomro, M., Khokhar, M., Hussain, W., & Hussain, M. (2011). Drinking water Quality challenges in Pakistan. Pakistan Council of Research in Water Resources, Lahore, 17-28.

Soylak, M., Aydin, F. A., Saracoglu, S., Elci, L., & Dogan, M. (2002). Chemical analysis of drinking water samples from Yozgat, Turkey. *Polish Journal of Environmental Studies*, 11(2), 151-156.

Treacy, J. (2019). Drinking water treatment and challenges in developing countries. The relevance of hygiene to health in developing countries, 55-77.