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Qualitative Assessment of Domestic Water Supply in the Major Districts of Karachi City for a Sustainable Urban Water Quality Management

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Abstract. The rising population, changing climate patterns and land use changes have emerged to be a serious consequence for the freshwater resources across the globe. Apart from water quantity, the water quality also holds a significant importance for the human health and the overall ecosystem. Due to the high population growth, massive migrations, and greater anthropogenic activities, the urban centers of the developing and underdeveloped countries are highly susceptible to water quality deterioration and waterborne diseases. Therefore, this study was conducted to assess the water quality of domestic water supply in the three (03) major and highly populated districts of Karachi, Pakistan including District Central, South, and East, receiving water from Keenjhar Lake via COD treatment plant. The physical test results showed higher turbidity levels (6.33 NTU) in Dhoraji (District East), 5.9 NTU in Boat Basin (District South), and 7.58 NTU in COD influent. Chemically, all samples showed satisfactory results as per the WHO guidelines. However, the biological water quality analysis showed significant presence of bacterial content (E-Coli and Total Coliform) in all collected samples. Conclusively, the treatment efficiency of COD treatment plant was found to be satisfactory and the contamination was mainly found due to the sewage and fecal mixing, presence of mud and silt in conduits, and leakage of sewage from the waste water pipes into the domestic water supply. The presence of harmful biological contaminants found in water is alarming, as it may consequentially lead to Diarrhea, vomiting, Typhoid, Cholera, and Jaundice. Thus, the research outcomes clearly unearthed the existing water quality of the mega city and would significantly serve to formulate well-integrated and holistic source water protection practices and to take effective measures for sustainable water quality management.

Keyword:
Human Health, Water Quality Management, Water Borne Diseases, Water Quality Parameters, SDG6.

1. Introduction

Water is the most abundant state of matter present on earth, constituting about 71% of the earth surface. Out of the total global water resources, about 97% of water is brackish (TDS between 3,000 ppm to 10,000 ppm) to saline (TDS above 10,000 ppm), while the remaining (3%) is freshwater (TDS below 3,000 ppm) [1]. Based on the natural distribution, about 68% of freshwater on earth is available as glaciers and ice sheets, 30% as groundwater, and 2% as surface water [2]. Apart from the importance of water quantity for the living beings, agriculture, industries, and hydropower generation, the water quality also holds a significant importance for the human health, crop production, marine life, and the overall ecosystem. Compared to the rural areas, the urban areas are more vulnerable to the water quality deterioration due to the higher population growth rate and migrations, dense transportation, high-impact development, and industries that yield significant environment degrading effluents. This necessitates a continuous monitoring of freshwater resources and its supply in the urban areas for drinking and other purposes for an effective water resources management.

Theoretically, the term “water quality” refers to the physical, chemical, and biological features of water and its fitness for a particular use (i.e., drinking, domestic use, livestock and agriculture, etc.) [3]. The major factors which threaten the water quality include the untreated discharge of effluents, absence of a well-researched water quality standard and monitoring mechanism, changing climate patterns, rising population, and land use alterations. As per the World Health Organization (WHO), poor hygiene habits, inadequate sanitation, and poor drinking water quality are the primary causes of 80% of infections [4].

For an effective assessment and monitoring of water quality, different physical, chemical and biological parameters of water are tested to ensure its fitness for a particular use. The factors that relate to taste, smell, touch, or sight are known as the physical parameters, with suspended solids, turbidity, colour, taste and odor, and temperature of water are the commonly tested physical parameters [5]. Suspended solids refer to the organic or inorganic solids or immiscible liquids (oil, grease, paint, etc.) that are in suspension in water [6]. Surface water often contains inorganic particles like rock sediments and soil, while the organic suspended matter including plant fibres, algae, bacteria, etc. which are also found in surface water. However, due to the soil filter action, suspended particles are seldom found in sub-surface water. Large amounts of suspended particles, primarily organic in nature, are also present in household wastewater. Similar to this, a variety of suspended contaminants, both organic and inorganic, are present in industrial discharges. Water with suspended particles is undesirable for a number of reasons. In the first place, it is visually unappealing and acts as an adsorption site for various biological and chemical substances. Furthermore, the suspended material can undergo biological degradation and produce undesirable by-products. The organisms that cause sickness, like algae, may be present in the biologically active suspended materials [7].

Turbidity refers to the cloudiness in water due to the presence of suspended solids, and is theoretically defined as the extent to which the light beam is reflected back due to the presence of suspended matter in the solution [8]. The erosive action of clay, silt, rock fragments, and metal oxides from the soil causes the majority of turbidity in surface water. Turbidity is also brought in by microorganisms and vegetable fibres. Upon discharge, domestic and commercial wastewaters also cause water bodies to turn turbid. Turbidity in waterbodies obstructs light penetration and photosynthetic reactions in the water, imparting brown or other color based on the suspended matter's light-absorbing qualities. Furthermore, sediment deposits created by the build-up of turbidity-causing particles in porous streambeds may have a negative impact on the stream's flora and fauna. In lab, turbidity is measured in Nephelometric Turbidity Unit (NTU). For drinking purpose, WHO recommends the turbidity to be less than 5 NTU [9].

Aesthetically, color gives a significant indication of water quality and presence of contaminants. Pure water is colourless by nature; however, the addition of other materials frequently causes it to become coloured. For example, iron oxides give water a reddish color, while manganese oxide gives it a brown or blackish hue. Significant coloration of the incoming water may also be caused by industrial effluents from the mining, food processing, pulp and paper, textile and dyeing, and other industries [10]. Apart from color, taste and odor, water temperature is also an important thermophysical property due to its influence on the biological organisms and their activity rates. In addition, it also affects chemical reactions in water. The water temperature is influenced by numerous factors, with the ambient air temperature being the most significant. Comparatively, shallow waterbodies are more vulnerable to the surrounding air temperature than the deeper waterbodies. The domestic and industrial wastewater containing harmful chemicals and radioactive waste drastically results in warm temperatures. Similarly, deforestation and return flows from irrigation carrying fertilizers and pesticides also results in warm water temperature, consequentially leading to reduced Dissolved Oxygen (DO) in water [11].

Chemically, the major parameters are Total Dissolved Solids (TDS), hardness, pH, alkalinity, and contamination of light and heavy metals. TDS generally refers to the solids (salts or minerals), liquids, or gases (NH_3, CO_2, Nitrogen, etc.) that are dissolved in water. Although salts, minerals, and nutrients in water are necessary for growth of human beings, but their excessive presence often leads to serious health issues. Like suspended solids, dissolved matter is also organic or inorganic. Metals, minerals, and gases are common examples of inorganic dissolved solids in water. In the atmosphere, on surfaces, or in the soil, water may come in contact with these materials. In contrast, dissolved organic matter in water is typically composed of organic compounds, decay products of vegetation, and organic gases [12]. Hardness refers to the presence of soluble bicarbonates, chlorides, and sulphates of Calcium (Ca) and Magnesium (Mg) in water. Hardness is categorized as temporary and permanent hardness. Temporary hardness is generally caused due to the bicarbonates of Ca and Mg in water and can be removed by boiling, where under high temperature, bicarbonates break down into insoluble carbonates, which are later removed by filtration. Permanent hardness is due to the soluble chlorides and sulphates of Ca and

Mg in water and cannot be removed by boiling [12].

In chemistry, pH (Potential of Hydrogen) is a quantitative measure of how acidic or basic a solution is, and is measured on the scale of 0 (most acidic) to 14 (most basic), with higher pH values show high basicity [13]. It is important to note that some bases are soluble in water, while some are insoluble. Alkali is a base that is soluble in water, and typically comprises of alkali and alkaline earth metals. Thus, all alkalis are base, but not all bases are alkali. Therefore, in simple words, alkalinity is the quantitative measure of the presence of oxides, hydroxides, and carbonates of alkali and alkaline earth metals in a solution, with higher alkalinity results in higher pH values. Heavy metals are the metals having higher density, atomic weight, and atomic numbers. Based on the density, heavy metals refer to the metals having density of above 5 gm/cm^3. The common heavy metals found in surface and groundwater includes Mercury (Hg), lead (Pb), Arsenic (Ar), Cadmium (Cd), and Chromium (Cr). These metals are toxic in nature and their contamination in water may pose severe health threats to the consumers [5].

Biologically, the presence of common water-borne bacteria and micro-organisms such as E-Coli and Total Coliform are tested. Around the world, a number of water quality standards are developed after years of experimental studies and tests and are being followed with particular guideline values set for each parameter for an effective water quality management, as shown in the Table 1. For instance, in USA, the guideline values for drinking, domestic use, and waste water discharges from different sources are generally determined by the United States Environment Protection Agency (USEPA) [8].

Table 1. Comparison of Guideline Values of Various Water Quality Parameters in Different Countries (Source: USEPA, 2023)

Parameter	WHO	EU	USA	China	Canada
Acrylamide (μg/L)	0.50	0.10	0.50	< 5.0	< 10.0
Aluminium (mg/L)	0.90	0.20	0.20	0.05–0.20	0.20
Antimony (mg/L)	0.02	0.005	0.006	0.005	0.006
Arsenic (mg/L)	0.01	0.01	0.01	0.05	0.01
Barium (mg/L)	1.3	2.0	2.0	2.5	1.0
Benzene (mg/L)	0.01	0.001	0.005	0.01	< 0.005
Boron (mg/L)	2.4	1.0	5.0	0.50	5.0
Bromate (mg/L)	0.01	0.01	0.01	0.01	< 0.01
Cadmium (mg/L)	0.003	0.005	0.005	0.005	0.005
Calcium (mg/L)	250	100	200	250	200
Chromium (mg/L)	0.05	0.05	0.1	0.05	0.05
Copper (mg/L)	2.0	2.0	1.3	1.0	1.0
Cyanide (mg/L)	0.07	0.05	0.20	0.05	0.20
Fluoride (mg/L)	1.5	1.5	4.0	1.0	1.5
Carbonate Hardness (mg/L)	500	400	150	400	80–100
Iron (mg/L)	< 0.3	0.20	0.30	0.30	0.30
Lead (mg/L)	0.01	0.01	0.01	0.01	0.01
Magnesium (mg/L)	150	25–50	100	50	50
Manganese (mg/L)	0.08	0.05	0.05	0.10	0.05
Mercury (μg/L)	6.0	1.0	2.0	0.05	1.0
Nitrate (mg/L)	50.0	50.0	10	10	< 45

Parameter	WHO	EU	USA	China	Canada
Nitrite (mg/L)	3.0	0.50	1.0	0.10	< 3.0
Total Pesticides (μg/L)	0.50	0.50	0.50	0.10	< 0.10
pH	6.5−8.5	6.5−8.5	6.5−8.5	6.5−8.5	6.5−8.5
Polycyclic Aromatic Hydrocarbons (μg/L)	0.10	0.10	0.20	0.20	0.004
Selenium (mg/L)	0.04	0.01	0.05	0.01	0.01
Silver (mg/L)	0.10	0.10	0.10	0.10	0.05
Sodium (mg/L)	200	250	200	<200	200
Tetrachloroethene and Trichloroethene (μg/L)	40	10	40	5.0	10.0
Uranium (mg/L)	0.03	0.03	0.03	0.002	0.1
Zinc (mg/L)	5.0	<3.0	5.0	< 3.0	5.0
Vinyl Chloride (μg/L)	0.50	0.50	0.20	< 1.0	< 2.0
Chlorides (mg/L)	250	250	250	< 200	< 250
Electrical Conductivity (μs/m)	400	2,500	1,500	< 1,000	2,500
Total Dissolved Solids (ppm)	< 1,000	< 500	< 500	< 500	< 500
Sulphate (mg/L)	250	250	250	< 200	< 500

Pakistan is listed among the countries having the highest rate of deaths and diseases due to the water-borne diseases. As stated in one of the studies, about 50 % of the diseases and 40% of the deaths in Pakistan are linked to poor quality of drinking water [9]. According to WHO, Diarrhea (a water-borne disease) has been found to be the leading cause of fatalities in infants and children in Pakistan, where one-fifth of every person in the country suffers from illness caused by the water pollution. Moreover, only about 25% of the country's population has a safe access to drinking water of acceptable quality [10]. The major factors censured for causing the water-borne disease in Pakistan include the untreated discharge of industrial, agriculture, and domestic effluents into the source water, contamination of municipal and industrial effluents in the domestic water supply giving birth to microbes, excessive use of fertilizers and pesticides on the agricultural sites percolating into the groundwater, and lack of efficient water treatment. As per the International Union on Conservation of Nature (IUCN), the prominent water-related diseases in Pakistan include Diarrhea, intestinal worms, Gastroenteritis, Typhoid, Giardiasis, and Cryptosporidium, with 60% of the infant's death in the country is caused due to Diarrhea [11]. Further, the microbial contamination has been identified as one of the serious problems in the urban as well as rural areas of Pakistan mainly due to the leakage of pipes, with pollution entering from sewage lines into domestic water supply. According to the Gross Operating Profit (GOP), the application of fertilizers and pesticides in Pakistan is about 5.6 million tons and 70,000 tons respectively, resulting in surface and groundwater contamination [12]. Further, the domestic and industrial effluents contain high concentrations of Arsenic that is emerging as a severe concern in Punjab and Sindh, with about 16% of the people are exposed to above 50 ppm of Arsenic [13].

Karachi, the largest city of Pakistan, has recorded a significant rate of population rise, where as per the Pakistan Bureau of Statistics (PBS), during 1950-2024, the city's population rose at a rate of nearly 0.25 million per year [14]. The rising population and land use changes have triggered a significant quantitative as well as qualitative threat to the freshwater resources in the city that needs to be comprehensively investigated for a sustainable environmental management. The inadequate water treatment and distribution, aged infrastructure, source water contamination, poor sanitation and wastewater management, and lack of public awareness and access to safe water are the key issues in the city. Karachi has experienced several health incidents linked to the poor water quality, resulting in illnesses and fatalities, where as per the Provincial Ministry of Health, in 2023, five deaths (05) were reported in city due to Naegleria fowleri, and two (02) deaths and over twenty-five (25) children fell ill due to Gastroenteritis Outbreak. The reported cases of illness and fatalities were mainly concentrated in district east and central of Karachi [13].

Therefore, the main objective of this research was to assess the quality of water supply from the largest treatment plant of Karachi (i.e., COD treatment plant) in the selected administrative districts of city (East, Central, and South). For this purpose, the area of Dhoraji was selected from the District East, Tariq Road and Liaqatabad from District Central, and Boat Basin and Bath Island were selected from District South. Methodologically, two (02) samples (one for the physical and chemical water quality analysis and other for biological analysis) were collected from each site. The sampling started from the influent at COD treatment plant coming from the Keenjhar Lake (Sindh) via Dhabeji pumping station, and two samples from effluent (post-treatment) from COD plant. The collected water samples were then tested in the water quality testing laboratory. The research outcomes are expected to capture the existing condition of water quality in the largest and most populated metropolitan city of Pakistan that may serve to devise a comprehensive source water protection approach and for a sustainable urban water quality management.

2. Methodology

2.1. Study Area

Karachi is the financial hub of Pakistan and the administrative capital of Sindh province, having the population of over 20 million and spanning on an area of about 3,530 km^2 as shown in the Figure 1. Geographically, Karachi is situated near Karachi Harbour along the coast of Sindh province in southern Pakistan. The city is situated in a plain along the coast that is dotted with hills, marshes, and rocky outcroppings. In the brackish seas of Karachi Harbour and further southeast toward the vast Indus River Delta, Mangrove forests thrive. The Cape Monze, referred to as Ras Muari locally, is located west of Karachi city and is distinguished by beaches, steep sandstone promontories, and sea cliffs. Geologically, Karachi is situated in close proximity to a significant fault line that separates the Arabian and Indian tectonic plates. Two tiny mountains, the Khasa and Mulri Hills, are located in Karachi's northwest and are part of the city [14].

Climatologically, based on the Koppen Climate Classification, Karachi has a hot desert climate (Bwh) dominated by hot summers and mild winters. Temporally, the mean monthly temperature of city ranges from highest in June (32.2 °C) to lowest in January (18.9 °C), with the mean annual temperature as 27.1 °C. Diurnally, the daily maximum temperature of Karachi often approaches 36 °C during May and June, while the daily minimum temperature drops to 12 °C in January. For precipitation, Karachi relies on the Southwest Summer

Monsoon, which contributes about 75% to its annual precipitation (i.e. 229.3 mm). During Monsoon season (July−September), Karachi receives 161 mm of rainfall every year on average. Administratively, Karachi is divided into seven (07) districts namely District East, South, West, Central, Korangi, Malir, and Keamari. For daily water requirement, Karachi relies on both surface and groundwater resources. The prominent surface water resources include Keenjhar Lake, Haleji Lake, and Hub Dam, whereas groundwater sources are the Dumlottee wells-field and the private tube wells. The Dumlottee well-field comprises of 12 wells and supply 5,300 m^3 per day during rainy season (July−September), while remain dry during rest of the year [15].

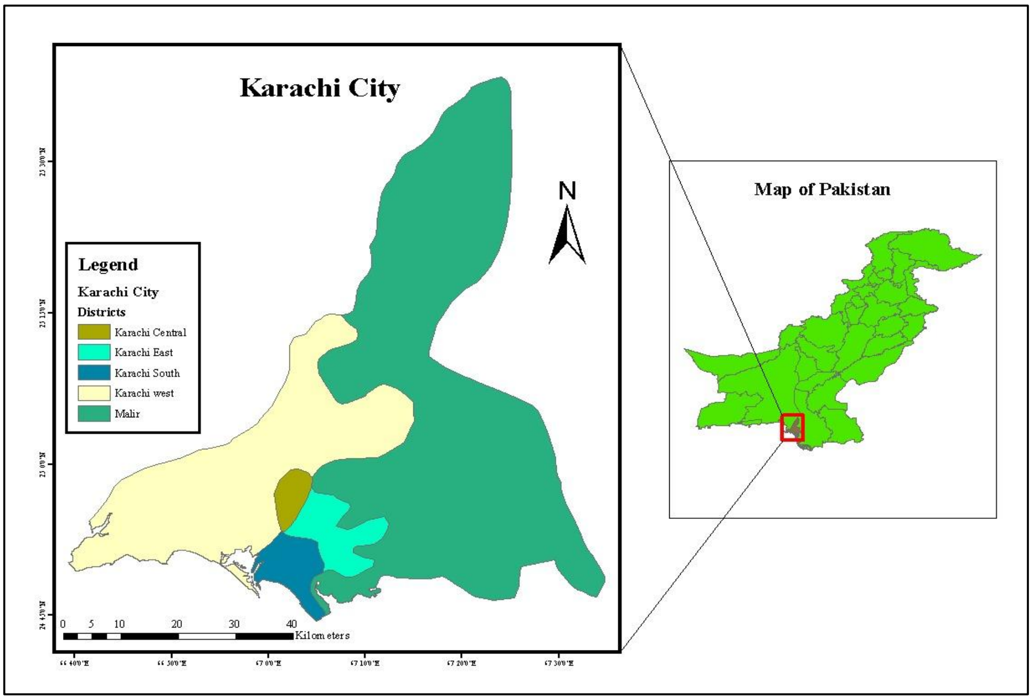

Figure 1. Description of study area.

From surface water resources, Karachi receives 2.86 −2.92 million cubic meter (MCM) per day of water against the demand of 5.72 MCM/day. Keenjhar Lake is an artificial lake formed by the union of Sunehri and Kalri Lakes in 1950s, with the major sources of water availability include monsoon seasonal rainfall and runoff from Indus River diverted via KB Feeder commencing from Kotri Barrage. The surface area of Keenjhar Lake is 98.5 km^2 and the water storage capacity as 627 MCM. From Keenjhar Lake, Karachi gets about 2.4−2.6 MCM/day of water. Haleji Lake is located about 70 km from Karachi in Thatta district of Sindh, fed by Keenjhar Lake and seasonal rainfall, and supplies 0.13 MCM/day to Karachi. The surface area of Haleji Lake is 17 km^2 and the water storage capacity is 13.21 MCM. Hub Dam is constructed on Hub River, located about 50 km northeast of Karachi and is the 3rd largest dam of Pakistan with gross, live, and dead storage capacities as 884, 810, 74 MCM respectively. The Hub Reservoir supplies water to both Balochistan (Lasbela district) and Sindh (Karachi). The dam is rainfed and supplies 0.2−0.4 MCM/day to Karachi via Hub Canal [16].

For raw water treatment, Karachi has five (05) major treatment plants including COD treatment plant, Pipri filter plant, old and new Northeast Karachi (NEK) plant, and Gharo filter plant. The COD treatment plant is the largest treatment plant of Karachi, which treats about 0.6 MCM/day of raw water coming from the Keenjhar Lake. The treatment plant supplies about 0.32 MCM/day to District East, 0.14 MCM/day to District South, and 0.26 MCM to District Central and West of Karachi [16].

2.2. Water Quality Sampling

In this study, for physical analysis, color, taste, odor, and turbidity were tested for each collected sample from the chosen sites shown in the Figure 2. For the biological water quality analysis, two (02) parameters including total coliform (cfu/ml) and E-coli (cfu/ml) were tested in the collected water samples. For the chemical analysis, a number of sixteen (16) parameters including Alkalinity (m-mol/L), Bi-carbonate (mg/L), Calcium, Magnesium, Potassium and Sodium in mg/L, Carbonates (mg/L), chloride (mg/L), Hardness as $CaCO_3$, Electrical conductivity (µ-s/m), Sulfate (mg/L), TDS (mg/L), Nitrate (mg/L), Fluoride (mg/L), Iron (mg/L), and Arsenic (ppb) were tested. A number of two (02) water samples (tap water coming from the COD treatment plant) were collected from each site, with one for the physical and chemical assessment and other for the biological assessment.

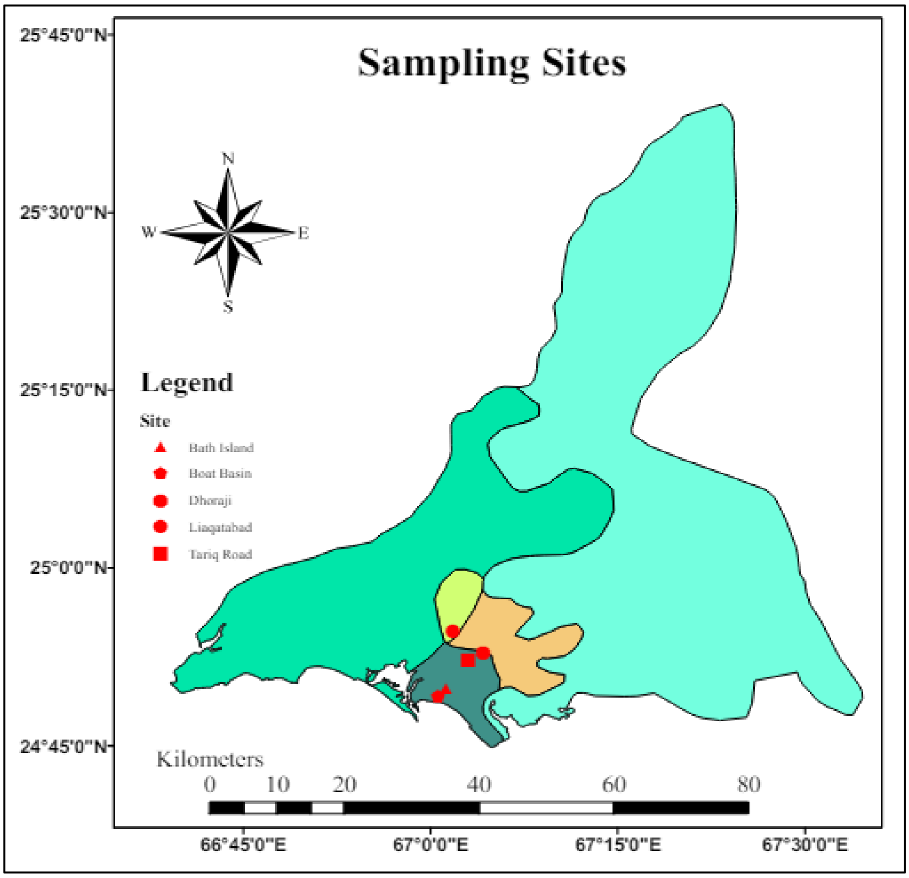

Figure 2. Description of sampling locations in the selected districts of Karachi.

2.3. On-Site Handling of Samples

While collecting the samples from the field, to ensure preservation and to keep the samples undisturbed from the external conditions, the water samples were collected in incubated bottles and were kept in a portable cooler containing ice (with temperature between 4 to 10 °C). For microbiological and chemical testing, austere preservation measured were practiced. For instance, for the microbiological testing (e.g., testing for coliforms, E. coli, or other bacteria), water samples were preserved to prevent the growth or death of microbes that could affect the test results. Like microbiological samples, chemical samples were also kept cool to minimize any chemical reactions or microbial activity. In addition, some chemicals, such as nutrients (e.g., nitrates, phosphates), degrade under light exposure. Therefore, the samples were kept in dark (using opaque portable box/cooler) until analysis.

Similar for the biological and chemical sample preservation, the samples were needed to be preserved for physical analysis. Although the physical parameters may not change as quickly as the chemical or biological characteristics, it is still good practice to keep the sample cool to avoid any temperature-related changes in properties. The sample bottles were filled to about ¾ to avoid overflow and to ensure enough space for sealing and the bottles were sealed tightly with a lid immediately after filling. The samples were transported shortly to the testing laboratory after collection.

2.4. Testing of Water Quality Parameters

The procedure adopted in the testing lab for testing the collected samples is elucidated in Table 2.

Table 2. Description of procedure adopted for testing the selected water quality parameters.

Parameter	Test/Equipment /Instrument	Description
Color	Colorimeter	A colorimeter is an instrument to measure the intensity of color in a water sample. The sample was collected in a clean clear container at room temperature. The instrument was calibrated using a pure water as a reference standard. The instrument was set to measure color at the appropriate wavelength (420 nm for yellow color, 455 nm for blue color, or 540 nm for greenish hues, depending on the expected color.
Odor	Descriptive Sensory Method (Standardized Odor Test)	The descriptive sensory method is the most common and basic way to test water odor. The sample was collected in a clean odor-free sealed container with an opening at room temperature. The samples were smelled directly with no deep sniff by gently inhaling the odor at a slight distance to prevent irritation or overwhelming odor perception. The odor intensity, usually on a scale from 0 (no odor) to 5 (very strong odor) was tested.
Taste	Descriptive Sensory Method (Standardized Taste Test)	The descriptive sensory method is a widely used approach for evaluating the taste of water. The sample was collected in a clean odor-free sealed container with an opening at room temperature. The intensity of the taste, on a scale from 0 (no taste) to 5 (very strong taste) was tested.
Turbidity (NTU)	Turbidity meter (Nephelometer)	Turbidity meter or Nephelometer is a commonly used instrument for measuring the turbidity. The instrument works by quantifying the amount of light scattered by the particles suspended in the water sample. The instrument was calibrated

Parameter	Test/Equipment /Instrument	Description
		using a turbidity standard solution with a known turbidity value. The instrument shines a light through the sample and measures the amount of light scattered in NTU.
Alkalinity (m-mol/L)	Titration Method	The titration process involves adding a titrant (a standard solution) to the water sample until a specific endpoint is reached. To measure total alkalinity, a two-step titration, which includes both Phenolphthalein Alkalinity and Methyl Orange Alkalinity was performed.
Bi-carbonate (mg/L)	Titration Method	To measure bicarbonates (HCO_3^-) in a water sample, alkalinity of water is determined, as bicarbonates are the main contributors to the total alkalinity. The process involved titrating the water sample to determine the concentration of bicarbonates and then subtract the values for phenolphthalein alkalinity (which represents the hydroxide and carbonate ions) from the total alkalinity to calculate the bicarbonate alkalinity.
Calcium (mg/L)	Titration Method	Calcium is typically present in water in the form of calcium ions (Ca^{2+}), and its concentration is often measured using titration methods, particularly with a complexometric titration using EDTA (ethylenediaminetetraacetic acid) as a titrant. This method is precise and widely used for determining the concentration of calcium in water. After performing the EDTA titration, the following expression was used for determining the calcium concentration: $$\text{Ca (mg/L)} = \frac{\text{Volume of EDTA (mL) x Molarity of EDTA} \left(\frac{\text{mol}}{\text{L}}\right) \text{X Atomic wieght of Ca x 1000}}{\text{Sample Volume (L)}}$$
Chloride (mg/L)	Titration Method (Mohr's Method)	One of the most common methods for measuring chloride in water is titration using a silver nitrate ($AgNO_3$) solution as the titrant. This is known as the Mohr Method, which is based on the reaction between chloride ions and silver ions to form silver chloride (AgCl). After performing the titration, the following expression was used for determining the chloride concentration: $$Cl^{-} \text{ (mg/L)} = \frac{\text{Volume of AgNO3 (mL) x Normality of AgNO3 N) X Atomic wieght of Cl}}{\text{Sample Volume (L)}}$$
Conductivity (µ-s/m)	Electrical Conductivity Meter	Before measuring the conductivity of sample, the conductivity meter was calibrated with a standard solution (Potassium Chloride) with a known conductivity value (i.e. 1413 µ-s/m at 25°C) for accurate readings. After calibration, the conductivity probe was fully immersed in the water sample without touching the bottom or sides of container to measure the conductivity of sample.

Parameter	Test/Equipment /Instrument	Description
Hardness as $CaCO_3$	Titration Method	Carbonate hardness was determined by measuring the concentration of carbonate ions (CO_3^{2-}) and bicarbonate ions (HCO_3^-) in the sample, through a titration method using a strong acid (0.02 N HCl) with Phenolphthalein indicator. After titration, the following expression was used to determine hardness: Carbonate hardness (mg/L) = $\frac{\text{Volume of HCl (mL) x Normality of HCl x 50,000}}{\text{Sample Volume (L)}}$
Magnesium (mg/L)	Complexometric titration	In lab, Mg concentration was determined by complexometric titration using an indicator (Eriochrome Black T) and 2 N EDTA as a titrant. This method is based on the principle that EDTA forms a stable complex with magnesium ions. After titration, the following expression was used to determine Mg concentration in water sample: Magnesium concentration (mg/L) = $\frac{\text{Volume of EDTA solution (mL) x Normality of EDTA x Molar mass of Mg}}{\text{Sample Volume (L)}}$
pH	pH meter	pH meter is a digital device for precise pH measurements. Before measurement, the pH meter was calibrated using a buffer solution of pH 7.0. After calibration, the pH probe was fully immersed into the water sample without touching the bottom or sides of container to measure the pH.
Potassium (mg/L)	Flame photometry Method	The flame photometry is the most common method for measuring potassium concentration in water, which is based on the principle that potassium atoms emit light at a characteristic wavelength when excited in a flame. The procedure incepted by first preparing the standard potassium solution of known concentration to calibrate the flame photometer by adjusting the instrument to match the potassium emission wavelength (around 766.5 nm). This was done by introducing the standard potassium solution into the flame, and the photometer measured the intensity of the emitted light. After this step, a calibration curve (intensity vs concentration) was made by running several standard solutions with known concentrations of potassium through the flame photometer, recording the intensity of the emitted light for each concentration. The curve was used to determine the potassium concentration in the water sample based on the intensity of the emitted light, with the intensity of emitted light being proportional to the concentration of potassium in the sample. Once the emission intensity was measured, the calibration curve was used to determine the potassium concentration in the sample.

Parameter	Test/Equipment /Instrument	Description
Sodium (mg/L)	Flame photometry Method	To measure sodium (Na^+) concentration in a water sample in the lab, the most common method is flame photometry (flame emission spectrophotometry). Sodium ions emit light at a specific wavelength when they are excited in a flame, and the intensity of the emitted light is proportional to the concentration of sodium in the sample. The procedure incepted by first preparing the standard sodium solution of known concentration to calibrate the flame photometer by adjusting the instrument to match the sodium emission wavelength (around 589 nm). After this step, a calibration curve (intensity vs concentration) was prepared by running several standard solutions with known concentrations of sodium through the flame photometer, recording the intensity of the emitted light for each concentration. The curve was used to determine the sodium concentration in the water sample based on the intensity of the emitted light. Once the emission intensity was measured, the calibration curve was used to determine the Sodium concentration in the sample.
Sulphate (mg/L)	Turbidimetric method (Barium Sulfate Precipitation)	One of the most widely used methods in the laboratory for measuring sulfate is the turbidimetric method, which involves reacting sulfate ions with a barium salt (e.g., barium chloride) to form barium sulfate, a precipitate that can be determined. The procedure commenced by first preparing a standard Sulfate solution (dissolve potassium sulfate) of known concentration. To form Barium Sulfate precipitate, a known volume of barium chloride solution was added to water sample. The amount of precipitate formed is proportional to the concentration of sulfate in the sample. After adding the barium chloride solution, the sample was allowed to stand for a few minutes to ensure that the barium sulfate has fully precipitated. After this step, the turbidity of solution was measured using turbidimeter, where turbidity is directly related to the concentration of sulfate ions in the sample.

Parameter	Test/Equipment /Instrument	Description
TDS (mg/L)	Gravimetric Method	To measure Total Dissolved Solids (TDS) in a water sample in the lab, gravimetric method is the most commonly used method, where TDS is determined by evaporating the water and weighing the remaining solids. The procedure commenced by cleaning the evaporation dish thoroughly and weighing it using an analytical balance. The procedure then followed preparing the water sample by taking its measured volume (100 ml) and pouring it into the evaporating dish. Once the water was completely evaporated, the evaporating dish was placed in a desiccator to cool it to room temperature. This prevents the solid residue from absorbing moisture from the air. After cooling, the evaporating dish was weighted with the remaining residue. After taking all the measurements, the TDS of water sample was quantified using the following expression: $$\text{TDS (mg/L)} = \frac{\text{Weight of residue (mg)}}{\text{Volume of Sample (L)}}$$
Nitrate (mg/L)	Colorimetric Method (using a spectrophotometer)	The colorimetric method is based on the reaction of nitrate with a specific reagent to produce a colored complex, which can be measured using a spectrophotometer at a particular wavelength. One widely used reagent is N-(1-naphthyl) ethylenediamine dihydrochloride (NED), which reacts with nitrate in the presence of sulfanilic acid to form a pink-colored compound. The procedure commenced by preparing a standard nitrate solution of known concentration and then diluting the standard solution to prepare a set of standard solutions with different nitrate concentrations to create a calibration curve. After this step, the known volume of the water sample was taken and transferred to a clean beaker. The sulfanilic acid solution was then added to the sample. Afterwards, NED solution was added to the sample, forming a pink-colored compound, with intensity proportional to the nitrate concentration. After this step, the sample was then transferred into a clean cuvette and then placed in the spectrophotometer. The spectrophotometer was then set to the wavelength of 540 nm, where the pink-colored product reached its maximum absorbance. The absorbance of the sample was measured at this wavelength. Using the measurements, a calibration curve (between nitrate concentration and absorbance) was constructed to measure absorbances. At last, the following expression was used to determine the nitrate concentration in the sample: $$NO_3^- \text{ (mg/L)} = (\text{Slope of curve x absorbance}) + \text{intercept}$$
Fluoride (mg/L)	Ion-Selective Electrode (ISE) Method	The Ion-Selective Electrode (ISE) method is one of the most direct and commonly used techniques for measuring fluoride in water by employing an ISE meter. The method commenced by calibrating the ISE by preparing standard fluoride solutions with

Parameter	Test/Equipment /Instrument	Description
		known concentrations and then calibrating the ISE by measuring the potential difference (voltage) for each standard fluoride solution. The ISE meter then generated a calibration curve of voltage (mV) versus fluoride concentration. After calibration, the ISE electrode was inserted into a known volume of water sample, allowing the potential to stabilize. The electrode selectively reacted with fluoride ions, generating a potential difference. Once the potential was stabilized, the ISE meter displayed the fluoride concentration based on the calibration curve.
Iron (mg/L)	Colorimetric Method (Phenanthroline Method)	The colorimetric method using 1, 10-phenanthroline is one of the most widely used techniques for measuring iron concentration in water. The method involves the reaction of iron with 1, 10-phenanthroline to form an orange-red complex, the intensity of which is proportional to the iron concentration. The procedure commenced by preparing a set of Iron standard solutions with known concentrations that were later used to construct calibration curve. After this step, a measured volume of 1, 10-phenanthroline reagent was added to the known volume of water sample. The sample was then transferred into a clean cuvette and the absorbance was measured at 510 nm using a spectrophotometer. Using the standard iron solutions, the absorbance values at 510 nm were measured and a calibration curve of absorbance vs. concentration was plotted. Based on the absorbance of water sample, the iron concentration was determined from the calibration curve.
Arsenic (ppb)	Hydride Generation Atomic Absorption Spectroscopy (HG-AAS)	Hydride generation atomic absorption spectroscopy (HG-AAS) is a highly sensitive method that is commonly used for measuring arsenic levels in water. This method uses a chemical reaction to reduce arsenic to its volatile hydride form, which is then introduced into the flame of an atomic absorption spectrometer. The procedure commenced by preparing the standard Arsenic solutions with known concentrations. After this step, sodium borohydride ($NaBH_4$) was added to the sample to reduce arsenic ions to arsine gas (AsH_3). To measure absorbance, the atomic absorption spectrometer was used to measure the absorbance of the flame at the appropriate wavelength (193.7 nm for arsenic), where intensity of absorption being directly proportional to the arsenic concentration. After this step, the calibration curve was plotted absorbance and concentration. Based on the absorbance, the concentration of Arsenic was determined in the water sample.

Parameter	Test/Equipment /Instrument	Description
Total coliform (cfu/ml)	Most Probable Number (MPN) Technique	The Most Probable Number (MPN) method is a widely used technique, especially when dealing with smaller water samples. It estimates the concentration of coliform bacteria based on statistical analysis of growth patterns in a series of tubes or wells. The procedure commenced by collecting known volume of the water sample. The method then followed the Inoculation of each test tube or well in the MPN kit with a specific volume of the water sample. A series of 05 tubes were inoculated, with the media used allowed coliforms to grow, with indicators for gas production or color changes. The tubes were then incubated for 24 hrs at 35°C. After incubation, gas production or color change was checked in the tubes. Gas production in the tubes (or a color change indicates the presence of coliforms. Based on the pattern of positive and negative results across the different dilution levels, a MPN table (available in standard methods manuals) was used to estimate the concentration of coliforms in the original sample.
E-coli (cfu/ml)	Most Probable Number (MPN) Technique	The Most Probable Number (MPN) method is a widely used technique to estimate the concentration of E. coli in water samples. The procedure commenced by collecting known volume of the water sample. The procedure then followed preparing a series of MPN tubes or wells with selective media. The test tubes or wells with the different volumes of water were inoculated. The tubes were then incubated at 44.5°C for 24 hours. After incubation, the test tubes were examined for gas production or color changes, which indicated the presence of E. coli. Based on the pattern of positive and negative results from the different dilutions, MPN table was used to estimate the most probable number of E. coli in the original sample.

3. Results and Discussion

3.1. Physical Water Quality Analysis

The results obtained from the laboratory testing were scrupulously analyzed under the light of WHO water quality guidelines. The analysis of physical quality parameters of the collected samples is shown in the Table 3 as under:

The table 3 showed that in the sample 1 (COD influent), the turbidity level was found to be higher (7.58 NTU) than the WHO guideline value (i.e., 5 NTU) and was remarked as unsatisfactory, while the remaining parameters were found to be within the recommended limit. In the post-treatment sample (Sample 2), the physical water quality results were found to be satisfactory with all parameters, i.e., found to be within the recommended limits. However, in Sample 3 (Dhoraji), the turbidity level was found to be higher (6.33 NTU) than the WHO guideline value, while all parameters in the Samples 4 and 5 collected from the central district were found to be satisfactory. The sample 6 collected from Boat Basin (District South) showed light brownish color and slightly higher turbidity (5.90) with reference to the WHO guideline value. As mentioned earlier, turbidity indicates the presence of silt, clay, organic pollutants (plant fibers and human waste) and inorganic matter in water. Therefore, the higher turbidity levels in water may interfere with the disinfection, and set a ground for the microbial growth in water that may also lead to reduced dissolved oxygen levels in water.

Table 3. Results of physical water quality analysis.

Parameter	Test Result	WHO Guide- line Value	Remarks
Sample 1: COD Influent			
Color	Colourless	Colourless	Satisfactory
Odor	Un-objectionable	Odourless	Satisfactory
Taste	Un-objectionable	Tasteless	Satisfactory
Turbidity (NTU)	7.58*	Less than 5	Unsatisfactory
Sample 2: COD Effluent (Post-treatment)			
Color	Colourless	Colourless	Satisfactory
Odor	Un-objectionable	Odourless	Satisfactory
Taste	Un-objectionable	Tasteless	Satisfactory
Turbidity (NTU)	3.62	Less than 5	Satisfactory
Sample 3: Dhoraji (District East)			
Color	Colourless	Colourless	Satisfactory
Odor	Un-objectionable	Odourless	Satisfactory
Taste	Un-objectionable	Tasteless	Satisfactory
Turbidity (NTU)	6.33*	Less than 5	Unsatisfactory
Sample 4: Liaqatabad (District Central)			
Color	Colourless	Colourless	Satisfactory
Odor	Un-objectionable	Odourless	Satisfactory
Taste	Un-objectionable	Tasteless	Satisfactory
Turbidity (NTU)	3.71	Less than 5	Satisfactory
Sample 5: Tariq Road (District Central)			
Color	Colourless	Colourless	Satisfactory
Odor	Un-objectionable	Odourless	Satisfactory
Taste	Un-objectionable	Tasteless	Satisfactory
Turbidity (NTU)	3.06	Less than 5	Satisfactory
Sample 6: Boat Basin (District South)			
Color	Light brownish*	Colourless	Unsatisfactory
Odor	Un-objectionable	Odourless	Satisfactory

Parameter	Test Result	WHO Guide- line Value	Remarks
Taste	Un-objectionable	Tasteless	Satisfactory
Turbidity (NTU)	5.90*	Less than 5	Unsatisfactory
Sample 7: Bath Island (District South)			
Color	Colourless	Colourless	Satisfactory
Odor	Un-objectionable	Odourless	Satisfactory
Taste	Un-objectionable	Tasteless	Satisfactory
Turbidity (NTU)	4.70	Less than 5	Satisfactory

***Shown in red: Test result exceeded the WHO guideline value**.

3.2. Chemical Water Quality Analysis

The results obtained from the chemical water quality analysis of collected samples are shown in the Table 4 as under:

Table 4. Results of chemical water quality parameter analysis

Parameter	Test Result	WHO Guideline Value	Remarks
Sample 1: COD Influent			
Alkalinity (m-mol/L)	2.2	NGVS	-
Bi-carbonate (mg/L)	110	NGVS	-
Calcium (mg/L)	32	200	Satisfactory
Chloride (mg/L)	71	250	Satisfactory
Conductivity (µ-s/m)	550	NGVS	-
Hardness as $CaCO_3$	120	500	Satisfactory
Magnesium (mg/L)	10	150	Satisfactory
pH	7.26	6.5-8.5	Satisfactory
Potassium (mg/L)	6.5	12 (E.C)	Satisfactory
Sodium (mg/L)	66	200	Satisfactory
Sulphate (mg/L)	55	250	Satisfactory
TDS (mg/L)	332	< 1000	Satisfactory
Nitrate (mg/L)	1.74	10	Satisfactory
Fluoride (mg/L)	0.19	1.5	Satisfactory
Iron (mg/L)	0.04	0.3	Satisfactory
Arsenic (ppb)	0.0	10	Satisfactory
Sample 2: COD Effluent (Post-treatment)			
Alkalinity (m-mol/L)	2.2	NGVS	-
Bi-carbonate (mg/L)	110	NGVS	-
Calcium (mg/L)	32	200	Satisfactory
Chloride (mg/L)	72	250	Satisfactory
Conductivity (µ-s/m)	545	NGVS	-
Hardness as $CaCO_3$	120	500	Satisfactory
Magnesium (mg/L)	10	150	Satisfactory
pH	7.32	6.5-8.5	Satisfactory
Potassium (mg/L)	6.2	12 (E.C)	Satisfactory
Sodium (mg/L)	64	200	Satisfactory
Sulphate (mg/L)	54	250	Satisfactory

Parameter	Test Result	WHO Guideline Value	Remarks
TDS (mg/L)	349	Less than 1000	Satisfactory
Nitrate (mg/L)	1.47	10	Satisfactory
Fluoride (mg/L)	0.21	1.5	Satisfactory
Iron (mg/L)	0.03	0.3	Satisfactory
Arsenic (ppb)	0.0	10	Satisfactory
Sample 3: Dhoraji (District East)			
Alkalinity (m-mol/L)	2.2	NGVS	-
Bi-carbonate (mg/L)	110	NGVS	-
Calcium (mg/L)	32	200	Satisfactory
Chloride (mg/L)	71	250	Satisfactory
Conductivity (µ-s/m)	540	NGVS	-
Hardness as $CaCO_3$	120	500	Satisfactory
Magnesium (mg/L)	10	150	Satisfactory
pH	7.41	6.5-8.5	Satisfactory
Potassium (mg/L)	6.1	12 (E.C)	Satisfactory
Sodium (mg/L)	65	200	Satisfactory
Sulphate (mg/L)	55	250	Satisfactory
TDS (mg/L)	346	Less than 1000	Satisfactory
Nitrate (mg/L)	1.595	10	Satisfactory
Fluoride (mg/L)	0.19	1.5	Satisfactory
Iron (mg/L)	0.04	0.3	Satisfactory
Arsenic (ppb)	0.0	10	Satisfactory
Sample 4: Liaqatabad (District Central)			
Alkalinity (m-mol/L)	2.1	NGVS	-
Bi-carbonate (mg/L)	105	NGVS	-
Calcium (mg/L)	32	200	Satisfactory
Chloride (mg/L)	73	250	Satisfactory
Conductivity (µ-s/m)	547	NGVS	-
Hardness as $CaCO_3$	120	500	Satisfactory
Magnesium (mg/L)	10	150	Satisfactory
pH	7.37	6.5-8.5	Satisfactory
Potassium (mg/L)	6.30	12 (E.C)	Satisfactory
Sodium (mg/L)	67	200	Satisfactory
Sulphate (mg/L)	56	250	Satisfactory
TDS (mg/L)	350	Less than 1000	Satisfactory
Nitrate (mg/L)	1.91	10	Satisfactory
Fluoride (mg/L)	0.17	1.5	Satisfactory
Iron (mg/L)	0.04	0.3	Satisfactory
Arsenic (ppb)	0.0	10	Satisfactory
Sample 5: Tariq Road (District Central)			
Alkalinity (m-mol/L)	2.2	NGVS	-
Bi-carbonate (mg/L)	110	NGVS	-
Calcium (mg/L)	32	200	Satisfactory
Chloride (mg/L)	75	250	Satisfactory

Parameter	Test Result	WHO Guideline Value	Remarks
Conductivity (µ-s/m)	558	NGVS	-
Hardness as $CaCO_3$	120	500	Satisfactory
Magnesium (mg/L)	10	150	Satisfactory
pH	7.39	6.5-8.5	Satisfactory
Potassium (mg/L)	6.4	12 (E.C)	Satisfactory
Sodium (mg/L)	70	200	Satisfactory
Sulphate (mg/L)	57	250	Satisfactory
TDS (mg/L)	357	Less than 1000	Satisfactory
Nitrate (mg/L)	1.29	10	Satisfactory
Fluoride (mg/L)	0.18	1.5	Satisfactory
Iron (mg/L)	0.03	0.3	Satisfactory
Arsenic (ppb)	0.0	10	Satisfactory
Sample 6: Boat Basin (District South)			
Alkalinity (m-mol/L)	2.2	NGVS	-
Bicarbonate (mg/L)	110	NGVS	-
Calcium (mg/L)	40	200	Satisfactory
Chloride (mg/L)	140	250	Satisfactory
Conductivity (µ-s/m)	558	NGVS	-
Hardness as $CaCO_3$	120	500	Satisfactory
Magnesium (mg/L)	30	150	Satisfactory
pH	7.40	6.5-8.5	Satisfactory
Potassium (mg/L)	6.0	12 (E.C)	Satisfactory
Sodium (mg/L)	100	200	Satisfactory
Sulphate (mg/L)	40	250	Satisfactory
TDS (mg/L)	500	Less than 1000	Satisfactory
Nitrate (mg/L)	3	10	Satisfactory
Fluoride (mg/L)	0.18	1.5	Satisfactory
Iron (mg/L)	0.05	0.3	Satisfactory
Arsenic (ppb)	0.0	10	Satisfactory
Sample 7: Bath Island (District South)			
Alkalinity (m-mol/L)	2.2	NGVS	-
Bicarbonate (mg/L)	110	NGVS	-
Calcium (mg/L)	50	200	Satisfactory
Chloride (mg/L)	170	250	Satisfactory
Conductivity (µ-s/m)	558	NGVS	-
Hardness as $CaCO_3$	160	500	Satisfactory
Magnesium (mg/L)	30	150	Satisfactory
pH	7.1	6.5-8.5	Satisfactory
Potassium (mg/L)	8.0	12 (E.C)	Satisfactory
Sodium (mg/L)	110	200	Satisfactory
Sulphate (mg/L)	60	250	Satisfactory
TDS (mg/L)	700	Less than 1000	Satisfactory
Nitrate (mg/L)	6.0	10	Satisfactory
Fluoride (mg/L)	0.18	1.5	Satisfactory
Iron (mg/L)	0.1	0.3	Satisfactory

Parameter	Test Result	WHO Guideline Value	Remarks
Arsenic (ppb)	0.0	10	Satisfactory

NGVS: No Guideline Value Set

The above results depicted satisfactory chemical water quality results in all samples, with all parameters found to be within the guideline limits of WHO.

3.3. Biological Water Quality Analysis

In this study, a number of two (02) major biological water quality parameters (i.e., E-Coli and Total Coliform) were examined in the collected water samples. The results obtained from the tests are shown in the Table 5 as under:

Table 5: Results of Biological water quality parameter analysis

Parameter	Test Result	WHO Guide line Value	Remarks
Sample 1: COD Influent			
Total coliform (cfu/ml)	52*	0.0	Unsatisfactory
E-coli (cfu/ml)	3.0*	0.0	Unsatisfactory
Sample 2: COD Effluent (Post-treatment)			
Total coliform (cfu/ml)	0.0	0.0	Satisfactory
E-coli (cfu/ml)	0.0	0.0	Satisfactory
Sample 3: Dhoraji (District East)			
Total coliform (cfu/ml)	40*	0.0	Unsatisfactory
E-coli (cfu/ml)	0.0	0.0	Satisfactory
Sample 4: Liaqatabad (District Central)			
Total coliform (cfu/ml)	TNTC**	0.0	Unsatisfactory
E-coli (cfu/ml)	0.0	0.0	Satisfactory
Sample 5: Tariq Road (District Central)			
Total coliform (cfu/ml)	TNTC**	0.0	Unsatisfactory
E-coli (cfu/ml)	15*	0.0	Unsatisfactory
Sample 6: Boat Basin (District South)			
Total coliform (cfu/ml)	90*	0.0	Unsatisfactory
E-coli (cfu/ml)	8*	0.0	Unsatisfactory
Sample 7: Bath Island (District South)			
Total coliform (cfu/ml)	100*	0.0	Unsatisfactory
E-coli (cfu/ml)	7.0*	0.0	Unsatisfactory

****TNTC: Too Numerous to Count**

The above results showed significantly higher amount of bacterial content in the water supply of all selected districts, where the highest amount of contamination was detected in the Samples 4 and 5 of Central District as TNTC (Too Numerous to Count). The test results in Sample 2 showed the efficient working of COD treatment with both biological parameters were reduced below the recommended limits after the treatment. However, the water supply was found to be polluted during conveyance from the distribution point on its way to the consumer. Based on the comprehensive field visit for sample collection, this contamination during the transmission was found to be mainly linked to the sewage and fecal contamination, presence of mud and silt in the inner surface of pipe, and leakage of sewage from the waste water pipes into the domestic water pipes. The presence of E-coli and Total coliform bacteria in domestic water is a significant health concern. E-coli infections can cause severe Diarrhea, often accompanied by abdominal cramps, nausea, and vomiting. Some strains of E-coli can produce toxins that lead to a potentially life-threatening condition. This affects red blood cells and can lead to kidney failure, especially in young children. Moreover, ingesting contaminated water can lead to general gastrointestinal distress, leading to conditions like stomach cramps, nausea, and vomiting.

Similar to E-Coli, total coliform contamination is linked to a variety of gastrointestinal diseases, including Diarrhea, dysentery, and cholera, which can cause severe illness, particularly in young children, the elderly, and those with weakened immune systems.

4. Conclusions

This comprehensive field-based research study was conducted to assess the quality of water supply in the three (03) major districts of the highly urbanized and densely populated Karachi City. The study effectively probed the exisitng alarming state of water quality in the city, where the water quality tests showed signficantly higher physical and biological contamination with reference to the WHO guideline. Conclusively, the study well explained the field-based approach of water quality assessment in an urban area, and the outcomes of this research are expected to effectively pave a way forward for conducting future research on water quality and can be conveniently applied to formulate an effective water quality management practice. Apart from the field-based or lab-based assessment of water quality of surface or groundwater resources, satellite-based (remote sensing) techniques are also being adopted across the globe, thereby relieving from the exhaustive field-based water quality assessment with less time and cost consumptions.

Recommendations

Based on the results obtained from the study, the following recommendations are furnished:

- Formulation of well-integrated, sustainable, and holistic water quality management and source water protection policies and strategies by the government agencies, water management authorities, and policymakers.
- The relevant government agencies and water management authorities should put a check on the industries and agricultural sector for the untreated discharge of sewage into water resources and bind them to recycle or practice safe disposal of sewage.
- Proper maintenance of water conveyance networks and reservoirs.
- Regular maintenance and inspection of sewerage infrastructure, established closer to the domestic water supplies.
- In order to reduce the bacterial content, Chlorine tablets can be used on the domestic level.
- In order to reduce the turbidity, Alum can be used on the domestic level.

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