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# Implementation Of Water Quality Index For Measuring Groundwater Quality

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## ABSTRACT

*Groundwater is one of the major sources of water consumption in developing countries. The aim of the study was to investigate the variations in physicochemical characteristics and metal content and to calculate the Water Quality Index (WQI) to assess the groundwater quality of seven districts (Central, East, West, South, Malir, Korangi, and Kemari) of Karachi City, Pakistan. A stratified sampling approach was used to collect groundwater samples and turbidity, pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Nitrate-N, and arsenic concentrations were investigated to profile WQI. The physicochemical parameters from districts South, West, Korangi, and Kemari were as per APHA standards and found suitable for drinking purposes. EC and TDS were in ranges of (2660-3870µS/cm) and (1596-2322mg/L) exceeding the standard limits resulting in poor drinking water quality respectively in districts Central, Malir, and East. These districts fail to meet the APHA standards and become unfit for human consumption on the WQI scale. However, TSS and arsenic was not detected in any of the collected samples. The correlation matrix for the[1] correlation coefficient (R-value) of tested parameters with WQI indicated significant linear and high R-value among tested parameters. The statistical analysis showed that turbidity, pH, EC, TDS, and Nitrate-N have significant effects on WQI. EC and TDS showed a direct correlation with WQI (R=1.0) whereas turbidity significantly correlates with the presence of nitrate in drinking water (R=0.64). These findings help the decision makers to plan mitigation strategies for comprehensive water quality monitoring of the respective areas and ensure the availability of clean and safe drinking water to the public.*

***KEYWORDS*** *WQI, water quality, pollution profile, Karachi.*

## HIGHLIGHTS

- significant variations in groundwater quality across Karachi's districts, with Central, Malir, and East exhibiting poor water quality due to high EC and TDS levels.

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- Groundwater in districts South, West, Korangi, and Kemari meets APHA standards, indicating suitability for drinking purposes.
- A strong direct correlation (R=1.0) between Electrical Conductivity (EC), Total Dissolved Solids (TDS), and Water Quality Index (WQI) underscores their critical role in assessing groundwater quality.

## 1 INTRODUCTION

Water is an essential environmental parameter that affects both humans and nature. The enhancement of water supply, sanitation, and efficient water resource management can positively impact economic development and significantly aid in the reduction of poverty [1]. The United Nations General Assembly approved the Sustainable Development Goals (SDGs) in 2015, which included SDG 6 that ensures the availability and sustainable management of water and sanitation for all [2]. It aims to improve access to safe and affordable drinking water, sanitation, and hygiene, as well as to promote the sustainable use and management of water resources globally. The SDG sets a target of achieving universal and equitable access to safe and cheap drinking water, and adequate and equitable sanitation and hygiene for all by 2030.

The availability of pure drinking water varies depending on geographical location. Around 4 billion individuals live in water-stressed countries, which is expected to be intensified due to climate change and population growth [3]. Karachi, the megacity and the economic hub of Pakistan, is facing a severe issue of poor access to clean drinking water. The city has seven districts (Central, East, West, South, Malir, Korangi and Kemari) [4], having an estimated population of more than 16 million people depending upon surface and groundwater sources for use [5]. The surface water sources are Hub Dam, Keenjhar, and Haleji Lake, while Dumlottee wells fall under groundwater resources [6]. However, a significant chunk of the population consumes drinking water that contains fecal coliforms, which is due to the mixing of sewer lines with drinking water pipelines due to old infrastructure [7]. The annual report for the year 2021 of the Pakistan Council of Research in Water Resources (PCRWR) claimed that 93% of the water sources are contaminated and unsafe for drinking purposes [8], while another report claimed that the per capita availability of water decreasing spontaneously and with this Pakistan falls under "water-stressed" country in upcoming years [9]. Due to reduced water supply, the illegal excess dwelling of wells and boreholes increases, resulting in groundwater level depletion [10].

Physicochemical parameters are important to identify the quality of water for its use. Turbidity, Potential Hydrogen (pH), Electrical Conductivity (EC), Total Dissolved Solids (TDS), and Total Suspended Solids (TSS) are those parameters which are mostly used to profile water quality [11]. Turbidity is measured as Nephelometric Turbidity Units (NTU) which quantifies the presence of suspended particles, plankton or micro-organisms causing cloudiness in water. The recommended value of turbidity is 5 NTU [12], extended value shows that water is not drinkable. The pH measures the acidity or alkalinity of water on a scale from 0 to 14 and is related to chemical quality of water. The standard value is 7 which shows neutral while values below 7 are acidic and above 7 is considered alkaline water [13]. EC serves as an indirect indicator of water quality. Changes in EC can signal variations in the composition of dissolved substances, such as salts, nutrients, and pollutants [14]. TDS measures the portion of total solids in a water sample that passes through a filter with a nominal pore size of 2 μm (or smaller) under specified conditions. It is represented as milligrams per liter (mg/L) or parts per million (ppm). It is recommended that TDS in drinking water does not exceed 1000 mg/L because high TDS levels can affect the taste and odor of water. Excessive dissolved minerals, such as salts, can impart a salty or bitter taste [15]. TSS refers to the concentration of particles that are suspended in water and can be trapped by a filter reported in mg/L [16]. However, the presence of nitrate and arsenic in drinking water can risk human health. Similarly, runoff from fertilized fields or seepage from septic systems can introduce nitrate or arsenic into groundwater, impacting drinking water supplies [17-18].

Health, hygiene, and access to safe drinking water are serious concerns in Karachi. The presence of physicochemical, and microbial contamination and metals in 42 groundwater samples makes water unfit for drinking. The microbial and physicochemical parameters from six districts (South, East, Central, West, Malir and Korangi) of Karachi City were tested in 2020 [19]. The results showed that the groundwater sample collected from District West was highly contaminated than the rest of the districts. The physical parameters like pH and turbidity lie within the standard limits, while the chemical contamination TDS, hardness and chloride exceed the limits in most samples. However, traces of metals were also found in the collected water samples, such as arsenic, cadmium, and lead, making them unfit for drinking.

Groundwater is becoming a naturally occurring resource of strategic significance due to rising demand, especially in metropolitan areas where water quality may be compromised [20]. Water Quality Index (WQI), Pollution Index (PI), Statistical methods for periodic assessments, and time-series analysis are available to profile the groundwater quality [21–23]. In this context, WQI is a promising tool to major the water quality parameters because of its simplicity [24] and frequently used method in developing countries [25–29]. WQI represents a unique way to interpret the quality of water by assigning a unique range for different purposes. It depends upon the quality rating scale (qi) and relative weight (wi). The qualitative rating scale is calculated using Equation 1, where $C_i$ is the calculated concentration of the water sample and $S_i$ is the standard permissible limit of the tested parameter [30].

$$q_i = \left(\frac{C_i}{S_i}\right) * 100 \qquad \text{Equation 1}$$

The relative weight ($w_i$) is the reciprocal of the permissible limit ($S_i$). WQI is calculated using Equation 2.

$$WQI = \frac{\sum(q_i * w_i)}{\sum(w_i)} \qquad \text{Equation 2}$$

Table 1 gives the range of WQI values for different purposes. It is noted that the WQI value > 100 is unfit for drinking purposes and needs possible treatment before consumption to reduce health risks.

**Table 1 WQI value and classification for drinking water [14]**

| **WQI value** | **Classification** |
|---|---|
| 0-25 | Excellent |
| 26-50 | Good |
| 51-75 | Poor |
| 76-100 | Very Poor |
| >100 | Unfit for drinking |

The key objective of the study was to capture variations in the quality of groundwater covering all districts (Centre, East, West, South, Malir, Korangi and Kemari) of Karachi city using the WQI method to analyze the quality of groundwater that the people are consuming in the vicinity of Karachi city. This study helps the decision makers to ensure the feasibility of clean drinking water to the population who do not have access to drinking water supply system and relying on well water for your daily consumption.

# 2 MATERIAL AND METHODS

## 2.1 Selection of Parameters

The physico-chemical parameters such as turbidity, pH, EC, TDS, TSS, Nitrate-N, and metal arsenic were selected to profile groundwater quality in seven districts of megacity, Karachi.

## 2.2 Sampling Strategy

A stratified sampling approach was used to collect groundwater samples. The stratified sampling strategy focuses to reveal the potential correlations between groundwater quality and proximity to potential contaminant sources [31]. Busiest area from each district (Table 2) was identified as unique strata based on the urbanized areas, agricultural zones, and locations near industrial sites such as North Nazimabad, and Gulshan-e-Iqbal are urbanized area whereas Baldia Town and Shah Faisal Town are located near the industrial area while Malir is near the agriculture zones and Defence and Kemari are situated near the Arabian Sea. The pin location and the corresponding area from each district are tabulated in Table 2. Within each identified stratum, groundwater samples were collected using a systematic random sampling approach. The bore depth of at least 70ft was used to analyze the concentration of contaminants. Figure 1 shows the sample collection points from each district. Analysis was conducted separately for each stratum, allowing for a detailed examination of groundwater quality within distinct geographical contexts. Findings were then compared across strata to draw conclusions about the overall groundwater quality trends and variations in the study area.

**Table 2: Location coordinates and the corresponding area of collection stations.**

| **District** | **Latitude** | **Longitude** | **Area** |
|---|---|---|---|
| **Central** | 24.914 | 67.029 | North Nazimabad |
| **East** | 24.929 | 67.128 | Gulshan-e-Iqbal |
| **West** | 24.938 | 66.961 | Baldia Town |
| **South** | 24.789 | 67.046 | Defence Phase V |
| **Malir** | 24.902 | 67.197 | Malir |
| **Korangi** | 24.876 | 67.156 | Shah Faisal Town |
| **Kemari** | 24.823 | 66.985 | Kemari Block 2 |


Figure 1: Location map of the collecting sample points indicating area selected from each district (Source: Generated using the pin location of the collecting point in MS-PowerBi)

## 2.3 Sample collection

The samples were collected during January-December 2023. Groundwater samples ( n= 10 in duplicate) were collected directly through borewells of depth 70ft-110ft from each district. Physical parameters pH and turbidity were tested in-situ using pH meter (model: MW101, manufacturer: Hach) and turbidity meter (model: 2100P, manufacturer: Hach), respectively. Samples were stored and labeled in two liter glass bottles and transported directly to the laboratory at an environmental temperature within 6 hours for further analysis as per the guidelines of America Public Health Association Protocols (22$^{nd}$ Edition) [32]. Samples were tested for arsenic using Merck 1.17927 guidelines [17]. The standard values for selected parameters were tabulated in Table 3. APHA does not provide any permissible limit of EC, hence used WHO standards for comparison.

## 2.4 Analysis of physicochemical parameters

For EC, conductivity meter (model: HI98303, manufacturer: Hanna) was used [14]. For TDS and TSS, a gravimetric analysis following the standard method was adopted. Initially, filter paper was pre-weighed before the filtration process. After the filtration was completed, the filtrate was cooked in a 100ºC oven until the filtrate was fully evaporated to get the weight of the residue denoting the TDS while the filter was removed and placed in the oven at 105 ºC to completely dry off the leftover water. The filter was then weighted to get TSS [15-16]. Briefly, for the determination of nitrate-N and arsenic, a UV-visible spectrophotometer-based standard method was used [17-18]. First, the standard solution of known concentration was used to measure the absorbance of each standard solution at a specific wavelength. Then the calibration curve was created by plotting the absorbance values against the known concentrations. Once the calibration curve was obtained, the sample was prepared and absorbance was measured to the calibrated curve to get the amount of nitrate and arsenic in the sample.

**Table 3: Details of parameters selected for groundwater pollution profile of Karachi City**

| S.No. | Parameters | Unit | Reference | Standard Value |
|---|---|---|---|---|
| 1 | Turbidity | NTU | APHA, 22nd Edition [12] | 5 |
| 2 | pH | - | APHA, 22nd Edition [13] | 7 |
| 3 | Electrical Conductivity (EC) | µS/cm | WHO [14] | 250 |
| 4 | Total Dissolved Solids (TDS) | mg/L | APHA, 22nd Edition [15] | 1000 |
| 5 | Total Suspended Solids (TSS) | mg/L | APHA, 22ndEdition [16] | 500 |
| 6 | Nitrate- N | mg/L | APHA, 22nd Edition [18] | 10 |
| 7 | Arsenic | ppb | Merck 1.17927 [17] | 50 |

### 2.4 Statistical Analysis

A correlation matrix was computed using Microsoft Excel to compare the observed value for each parameter for each district.

## 3 RESULTS AND DISCUSSION

### 3.1 Analysis of physicochemical and metal characteristics

The physicochemical parameters were tested and analyzed for all the collected groundwater samples and tabulated in Table 4. Each district was compared against all parameters to generate the WQI for Karachi city.

The samples tested for turbidity from district Central (1±0.84), West (1±0.07), South (1±0.18), Malir (1±0.05), Korangi (1±0.61) and Kemari (1±0.54) were below the standard value of 5 NTU resulting in clear aesthetic water except for district east in which a relatively higher value of 22±2.0 NTU was observed as shown in Figure 2. Turbidity occurred due to the presence of soil, organic and inorganic matter, and other microscopic organisms. Due to the runoff of rainwater and the increase in soil erosion, there is increased turbidity in natural water sources [33-34]. This might be the reason which leads to the elevated levels of turbidity in District East.

**Table 4: Results of water quality parameters in collected samples from each district of Karachi**

| S.No. | District | Physicochemical Parameters | | | | | | Metal |
|---|---|---|---|---|---|---|---|---|
| | | Turbidity | pH | EC | TDS | TSS | Nitrate-N | Arsenic |
| 1 | Central | 1±0.84 | 8±0.03 | 2660±80 | 1596±30 | ND | 10±0.98 | ND |
| 2 | East | 22±2.0 | 7±0.39 | 3870±90 | 2322±80 | ND | 4±0.48 | ND |
| 3 | West | 1±0.07 | 7±0.52 | 699±60 | 419±20 | ND | 1±0.83 | ND |
| 4 | South | 1±0.18 | 7±0.70 | 921±30 | 553±40 | ND | 1±0.77 | ND |
| 5 | Malir | 1±0.05 | 7±0.74 | 3510±95 | 2106±70 | ND | 5±0.58 | ND |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 6 | Korangi | 1±0.61 | 7±0.62 | 818±20 | 491±10 | ND | 1±0.81 | ND |
| 7 | Kemari | 1±0.54 | 7±0.45 | 706±10 | 424±15 | ND | 1±0.76 | ND |

Key: ND = not detected

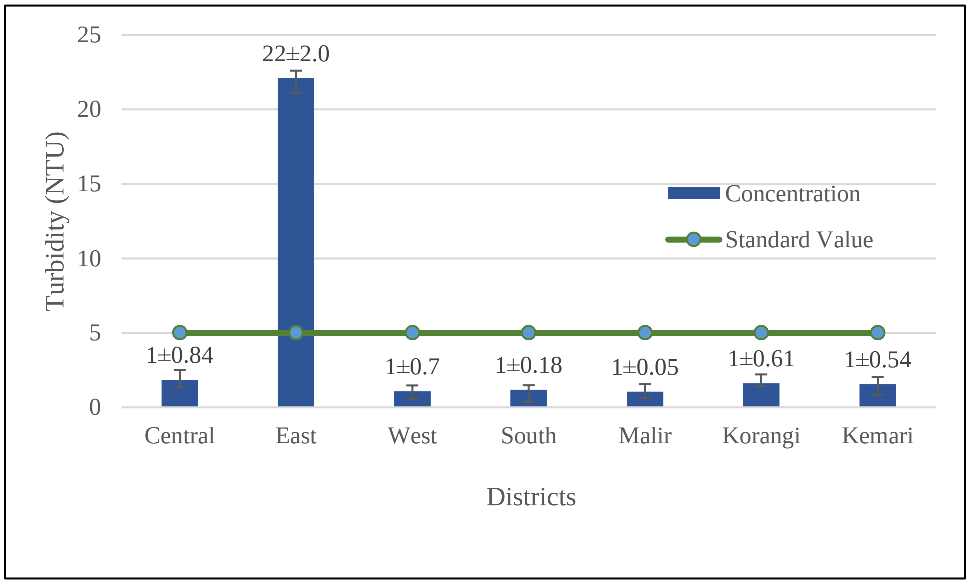



**Figure 2 Turbidity variations in water samples collected from each district of Karachi.**

The observed values of pH (Figure 2) in each sample were more inclined towards alkalinity because the obtained values were greater than the standard value (pH=7.0), while the pH in district central is relatively higher (8±0.03). However, the lowest value of pH=7±0.39 is observed in district East as compared to the rest of the samples.

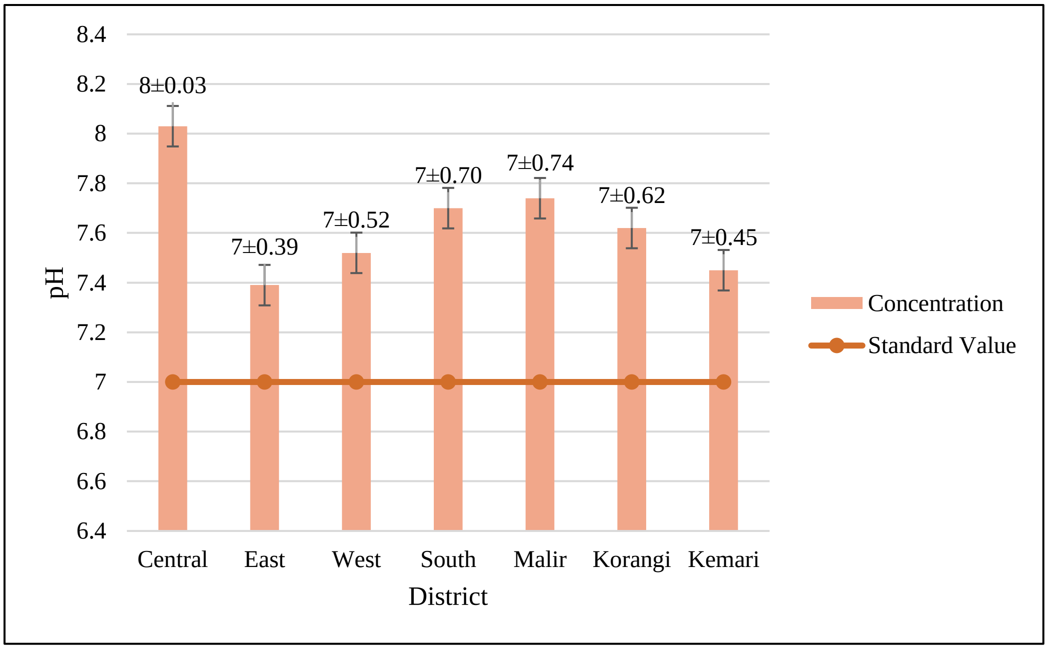
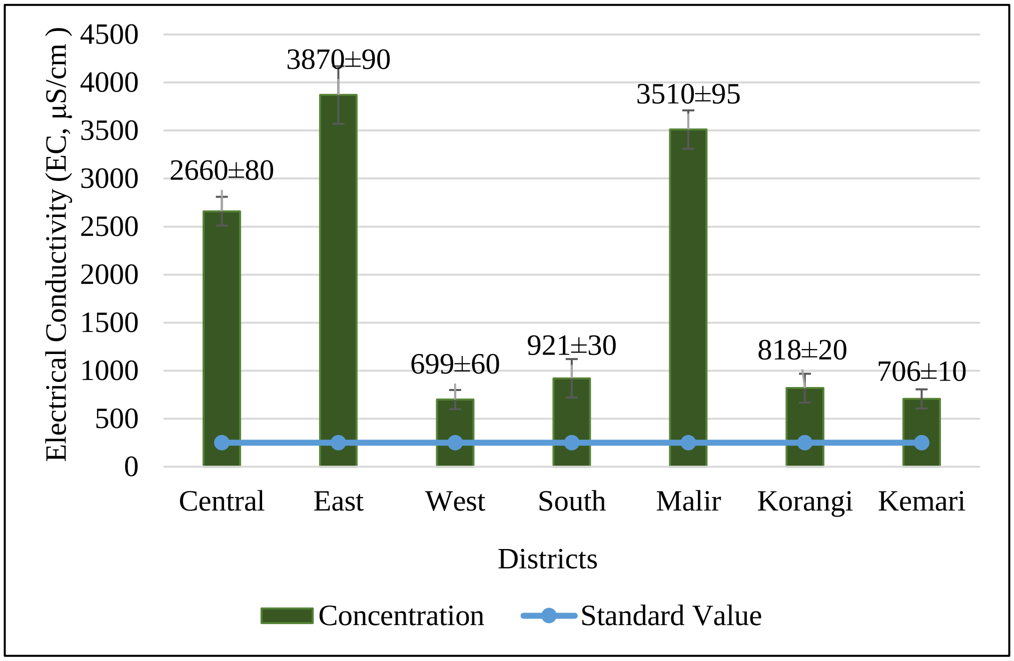
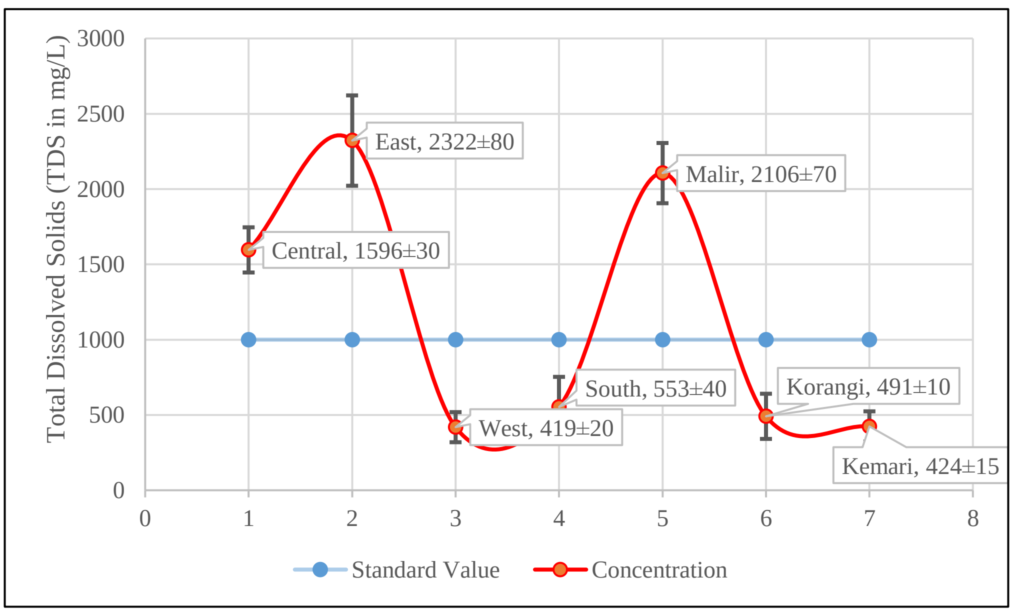



Figure 2: pH in water samples collected from each district of Karachi.

Higher alkalinity in water can contribute to a higher pH because alkalinity is related to the presence of bicarbonate, carbonate, and hydroxide ions [35]. In some cases, high alkalinity might also be associated with an increase in EC, especially if the alkalinity is due to dissolved salts [36-37]. The analysis (Figure 3a) shows that all the collected groundwater samples tested for EC exceed the standard value which is 250µS/cm that indicates the presence of dissolved solids in groundwater. However, the values obtained for districts Central, East, and Malir had relatively higher EC (2660±80, 3870±90, and 3510±95µS/cm) than the rest of the districts. EC is also used for the indirect estimation of TDS. It is also observed that the districts Central, East, and Malir which have higher EC values also have elevated TDS levels i.e. 1596±30, 2322±80, and 2106±70mg/L, respectively as shown in Figure 3(b). It also indicates the presence of dissolved salts in groundwater samples. However, TSS is not detected in any of the collected samples indicating the filtration of TSS from the soil layers.




(a)




(b)

Figure 3: Water samples collected from each district of Karachi for (a) EC, and (b) TDS.

The ground water samples tested for nitrates from each district were under the prescribed limit which is 10mg/L while only the sample collected from district central exceeded the limit by 0.981mg/L shown in Figure 4(b), which showed the need for treatment before consumption. Furthermore, arsenic was not detected in any of the collected samples.

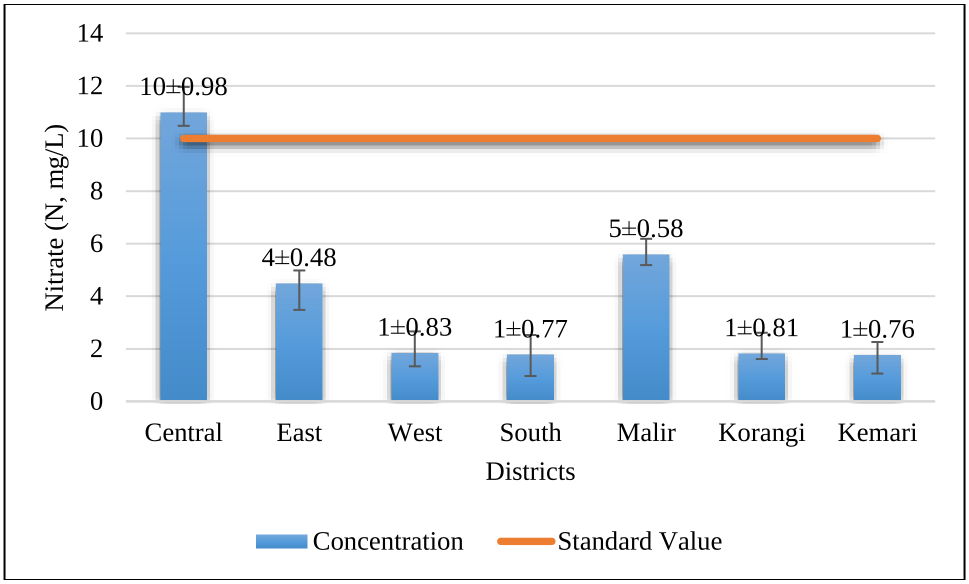



Figure 4: Concentration of Nitrate in drinking water samples from wells of seven districts of Karachi (in mg/L)

## 3.2 Groundwater pollution profile of Karachi city based on WQI

The WQI was calculated using Equation 2. It was observed that the samples collected from District Central, East and Malir had relatively high WQI values of 131, 190 and 172 which make them unfit for drinking purposes and require appreopriate and planned treatment (Table **5**). The higher values in these districts are also predicted because the parameters tested from these districts mostly exceeded the standard range resulting in the higher values. Similarly, the rest of the districts like West, South, Korangi and Kemari observe relatively similar values not in excellent range but still acceptable and fit for drinking purposes with primary precautions (Table **5**).

## 3.3 Statistical analysis of water quality parameter

A correlation matrix of selected water quality parameters, namely, turbidity, pH, EC, TDS, Nitrate-N among themselves and with water quality index (WQI) was analyzed and tabulated in Table 6. Turbidity showed a positive linear correlation with EC and TDS (0.62) while exhibiting a moderate positive correlation with Nitrate-N (0.08) as their correlation coefficient (R-value) is in mid-range from -1 to 1. However, it showed a moderate negative correlation with pH (-0.49). It is also observed that EC and TDS are interrelated as the correlation matrix showed (Table 6) the R-value is exactly equal to 1, hence it is said that TDS and EC has a direct linear relation among them. It is also observed that the remaining parameters have moderate positive linear correlation as tabulated in Table 6. The table also gives the relation of water quality parameters and WQI values. It is observed from the analysis that EC and TDS have direct impact on the water quality index while turbidity and nitrate have a positive linear relation with WQI as their R-values are 0.62 and 0.64, respectively. However, it exhibits a moderate relation with pH (0.16).

**Table 5: Assessment of the water quality of each district based on the Water Quality Index (WQI).**

| District | WQI Value | Water quality classification based on computed WQI values in sample sites |
|---|---|---|
| **Central** | 131 | **Unfit for drinking** |
| **East** | 190 | **Unfit for drinking** |
| **West** | 34 | Good |
| **South** | 45 | Good |
| **Malir** | 172 | **Unfit for drinking** |
| **Korangi** | 40 | Good |
| **Kemari** | 35 | Good |

Key: Water quality classification based on WQI values range (0-25 = excellent; 26–50 = good water; 51–75 = poor water; 76–100 = very poor water; >100 = water unsuitable for drinking)

Table 6: Statistical analysis of water quality parameter to WQI value

| | Turbidity | pH | EC | TDS | Nitrate- N | WQI Value |
|---|---|---|---|---|---|---|
| **Turbidity** | 1.00 | | | | | |
| **pH** | -0.49 | 1.00 | | | | |
| **EC** | 0.62 | 0.16 | 1.00 | | | |
| **TDS** | 0.62 | 0.16 | 1.00 | 1.00 | | |
| **Nitrate- N** | 0.08 | 0.75 | 0.64 | 0.64 | 1.00 | |
| **WQI Value** | 0.62 | 0.16 | 1.00 | 1.00 | 0.64 | 1.00 |

### 3.4 Physicochemical Contamination

The physical, chemical, and microbial characteristics of water differ from place to place, defining water quality. It is crucial to identify the specific water-quality traits that impact future water uses when assessing the quality of natural water sources used for diverse purposes. Rains, industrial waste disposal, chemical weathering of rocks, and other variables can change the properties of groundwater [38]. Contaminants infiltrating groundwater present significant challenges in detection and removal, as they are often indistinguishable by taste or smell. Consequently, these contaminants have the potential to contaminate groundwater used for both irrigation and drinking purposes. A study conducted in Gulshan-e-Iqbal town in Karachi in 2013 showed that 90% of the borehole samples comply with the standard limits, while the microbiological characteristics of 70% of groundwater samples were found satisfactory for potable water [38]. A similar study in the SITE area showed that the groundwater is mainly saline and 80% of samples contain TDS above 500 ppm [29]. Table 7 summarizes the results of the studies done in Karachi city within two years to monitor the status of groundwater.

**Table 7: Summary of the studies conducted in the last three years (2020-2022) in Karachi**

| **Year** | **Location** | **Reference** | **Sample Collection** | **Results** | | |
|---|---|---|---|---|---|---|
| | | | | pH | Turbidity (NTU) | TDS (mg/L) |
| 2022 | Karachi | [29] | 24 | 7 | - | 5978 |
| 2022 | Sialkot, Lahore and Karachi | [39] | 35 | 7.59 | - | 1308 |
| 2020 | Karachi | [19] | 42 | 7.29 | 0.269 | 2452.74 |
| 2020 | Model Colony Karachi | [26] | N.M | 7.47 | 0.59 | 327.75 |
| 2020 | Karachi | [40] | N.M | 7.29 | 0.269 | 2452.74 |
| 2020 | Karachi | [41] | 28 | 7.006 | - | 11946 |

Key: N.M= Not mentioned

## 4 CONCLUSION

The conducted study provides a cureent overview of the quality of groundwater of Karachi City. The samples tested from Defence Phase V, Baldia Town, Korangi, and Kemari largely comply with APHA recommendations and can be considered safe for drinking, while samples from Gulistan-e-Johar, Malir Cantt, and North Nazimabad reveal concerning deviations.

Gulistan-e-Johar exhibits alarmingly high turbidity (22.1 NTU) as shown in **Error! Reference source not found.** while relatively elevated values were observed in TDS as most of the area exceeds the standard range like TDS level of 2322 mg/L was observed in District East (Figure 3), exceeding safe limits and rendering the water unsuitable for consumption. Similarly, District Malir the potential health risks associated with chronic consumption of such water, including gastrointestinal issues and unpalatability, cannot be ignored. It can pose the risk for Blue Baby Syndrome and thyroid issues and needs immediate action to address this contamination and safeguard public health.

In conclusion, these findings underscore the urgency for comprehensive water quality monitoring in the city of Karachi, targeted intervention strategies, and public awareness campaigns. Ensuring access to safe water is not merely a matter of convenience; it is a fundamental human right and a cornerstone of public health. By addressing the identified water quality issues, decision-makers can safeguard the well-being of present and future generations and achieve SDG 6.

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