# Use of Water Quality Index and GIS for Assessing and Mapping the Quality of Groundwater of Taluka Kotdiji, Sindh, Pakistan

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## Abstract

*Groundwater is broadly consumed around the globe, including in Taluka Kotdiji, Sindh, Pakistan, for drinking and irrigation purposes. Taking into consideration the issues of civil society of Taluka Kotdiji, Sindh about groundwater vulnerability, the research was carried out to estimate and delineate the quality of groundwater based on analysis results of physicochemical parameters (pH, turbidity, electrical conductivity (EC), chlorides (Cl), calcium (Ca), magnesium (Mg), total hardness (TH), and total dissolved solids (TDS)) and application of water quality index (WQI) and ArcGIS software. The results of physicochemical parameters revealed that 56.41%, 23.07%, 35.89%, 20.51%, 10.25% and 56.41% of the samples EC, Ca, Mg, TH and TDS concentrations exceeded the WHO limits. Based on the WQI model, no water sample was in the excellent category; however, 64.1%, 28.2%, 5.1%, and 2.6% of the samples fall in good, poor, poor and unsuitable for drinking categories. The GIS maps depicted that water quality on the South-Eastern side of the study area is vulnerable. The study revealed that water quality in several parts of Taluka Kotdiji does not align with the WHO guidelines. It must be purified well before being used for drinking. A campaign should be carried out to make people aware of groundwater vulnerability and its effects on health.*


**Keywords:** Groundwater Vulnerability, Physicochemical Parameters, Thematic Maps.

## Introduction

Groundwater is the primary source used in arid and semi-arid parts of the world for drinking and irrigation applications (Li et al., 2019). Shen et al. (2008) reported in their research that more than 1.5 billion people around the globe rely on groundwater in direct or indirect ways. Groundwater demand has increased dramatically in the last 20 years due to insufficient surface water provision in semi-arid areas and drinking and irrigation intake in many parts of the world (Adimalla & Li, 2019).

The need for sweet water has strangely increased in the last few decades due to rapid population growth and quick industrial development (Ramakrishnaiah et al., 2009). Managing water resources properly is a serious concern all over the world. Globally, groundwater is accepted as the principal source of fresh water for numerous causes around the globe. Environmental changes, population growth, urbanization and industrialization have highly affected

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groundwater pollution complications in different regions of the world (Yolcubal et al., 2016; Tyagi et al., 2013).
Pakistan ranks third globally for groundwater use, with almost 9 per cent of groundwater extraction (Giordano, 2009). Assess the physical, chemical, and biological characteristics and range of impurities of surface and groundwater to know their suitability for different uses (Asghari et al., 2018).
Water quality evaluation worldwide has become a thoughtful issue in emerging nations. Both the quantity and quality of groundwater have equal importance. Water quality evaluation is a dynamic part of the environmental quality mechanism that is equally essential for human beings as well as for the existence of the environment. Among the prime objectives of Sustainable Development Goals (SDGs) providing safe and cost-effective drinking water to every user is one of the primary objectives. Offering secure and clean water to everybody is one of the fundamental rights irrespective of their nation, religion, colour, prosperity or belief in drinking (Li & Wu, 2019). This has engaged researchers around the world to increase focus on the examination of groundwater quality. Among the 122 nation-states in the world, Pakistan is listed as 80th on the water quality basis (Sanjrani et al., 2018; Azizullah, 2011; UNESCO, 2002). Like other regions of Pakistan, the water quality in Sindh Province is also poor. Like other states of Pakistan, the water quality in Sindh Province of Pakistan is unsafe for drinking. Many available water is contaminated with pathogens, chemicals, and toxic materials.
Pakistan fulfils its water demands from the water of the Indus River system. Pakistan has become a water-stressed nation over the last decade (Mustafa et al., 2013; Kirby & Ahmad, 2014). Contaminated water for drinking can primarily affect people's environment and health (Li & Wu, 2019; Mgbenu & Egbueri, 2019). It has been reported globally that annually, about 1.8 million people pass away due to diarrheal diseases; the most common reason for these diseases is the use of polluted water for drinking. (WHO 2005; Forstinus et al., 2015). However, plotting groundwater quality is one method that shows information about its appropriateness for several usages, such as drinking and irrigation. The WQI is a beneficial and appropriate mathematical model that can be used to analyze and gain knowledge about water quality (Omran, 2012). To ensure water quality, WQI is used by many scholars worldwide (Solangi et al., 2018). Hence, to examine and plot groundwater quality, it is compulsory to identify its degree of pollution. Thus, the present research has been conducted in Kotdiji Taluka of Khairpur District to estimate and outline groundwater quality by applying the WQI model and GIS practices.

## Literature Review

Nassar et al. (2025) said that groundwater is the second most significant freshwater source in the Assiut area, serving all sectors, including the industrial, agricultural, and domestic sectors. Water quality assessment involved evaluating 16 parameters and comparing them to drinking water and irrigation standards set by the Organization of World Health (WHO) and the Egyptian Specifications (ES). In this study, eight main parameters are selected due to their importance, which are Electrical Conductivity (EC), pH, Total Dissolved Solids (TDS), Nitrate ($NO_3^-$) and Fluoride ($F^-$). The analysis indicates that groundwater is not entirely suitable for drinking, particularly regarding TDS, Chemical Oxygen Demand (COD), and Total Organic Carbon (TOC). In particular samples, the parameter concentrations surpass the allowable limits defined by WHO and ES. This is due to increased domestic and industrial wastewater discharge the stretch, other harmful anthropogenic activities and human interventions. GIS-based spatial analysis successfully identified vulnerable areas where groundwater contamination is most severe. Elevated TDS, COD, and TOC levels were found in several locations, posing domestic use and irrigation risks. The Piper diagram analysis indicated that the predominant water type is calcium-chloride-bicarbonate, suggesting groundwater is influenced by precipitation and water-rock interactions with carbonate rocks. The Water Quality Index (WQI) analysis was applied, showing that the northern part near the New Assiut Barrage (samples 10 and 11) exhibits a high degree of contamination, making the water unsuitable for drinking according to WHO and Egyptian standards.

El-Rawy et al. (2024) stated that assessing water quality in arid regions is vital due to scarce resources, impacting health and sustainable management. This study examines groundwater quality in Assuit Governorate, Egypt, using Principal Component Analysis, GIS, and Machine Learning Techniques. Data from 217 wells across 12 parameters were analyzed, including TDS, EC, $Cl^-$, $Fe^{++}$, $Ca^{++}$, $Mg^{++}$, $Na^+$, $SO_4^{--}$, $Mn^{++}$, $HCO_3^-$, $K^+$, and pH. The Water Quality Index (WQI) was calculated, and ArcGIS mapped its spatial distribution. Machine learning algorithms were used for predictive analysis, including Ridge Regression, XGBoost, Decision Tree, Random Forest, and K-nearest neighbours. Higher Na, K, Ca, Mg, Mn, and Fe concentrations correlated with industrial and densely populated areas. Most samples exhibited excellent or sound quality, with a small percentage unsuitable for consumption. Ridge Regression showed the lowest MAPE rates (0.22 % in training, 0.26 % in testing). This research highlights the importance of advanced machine learning for sustainable groundwater management in arid regions.

Carasek et al. (2020) assessed the groundwater quality of Santa Catarina state at the Serra Geral Aquifer system (SGAS). For this purpose, 100 tube wells from rural and urban areas were selected. To assess the physicochemical parameters such as Cu, Cd, Mn, pH, Mg, Fe, Zn, $NO_3^-$, Pb, $NO_2^-$, $NH_4^+$, EC and Turbidity 300 samples were obtained in March, September and November 2014. The levels of Fe and Mn were 31% and 85%, respectively, which show very high levels of metals and do not meet the standards of Brazil Ministry of Health Decree 2.914 of 2011 for human consumption. The results showed that Pb, Cu, Mg, Cd, Zn, and Nitrogen compounds meet the established standards of Brazilian regulations.

Adimalalla et al. (2020). India's groundwater is reported to be the only source of drinking and irrigation for residents of central Telangana. Due to rapid population growth and substantial irrigation applications, groundwater pressure has increased, existing groundwater has decreased, and water quality has declined. One hundred-five groundwater samples were obtained and analyzed from semi-arid areas of the study area to assess the quality of their drinking water and irrigation activities. Based on the results of pH, TH, $Mg^{2+}$, $Na^+$, $CaCO_3$, EC, $Ca^{2+}$, TDS, $K^+$, $Cl^-$, and SO24, it was determined that most of the water in the study area is fit for drinking intake. Almost 51% of Fluoridefluoride and 71% of nitrate samples in groundwater were beyond the maximum allowable limits. Hence, it is recommended that due to high Fluoride and nitrate concentrations, the water should not be used for drinking.

Das et al. (2020) collected 110 groundwater samples from 17 blocks of Nadia district located in West Bengal to assess groundwater's physical and chemical characteristics and determine its quality. The range of average concentration of anions in groundwater falls in the order of HCO-3> Cl-> CO2-3> SO2-4> NO-3> PO3-4, which shows that the quality groundwater of Nadia district is entirely alkaline, which is primarily due to the bicarbonate alkalinity. Calcium and magnesium ions determine the hardness where $Ca^{2+}$ ion concentration overrides the $Mg^{2+}$. Arsenic contaminations are found in all the blocks, and a large amount of arsenic concentration determined is 206 μg/l in Chakdah. Some groundwater samples have obtained high nitrate levels, mainly in Krishnanagar-I, Nabadwip, Kaliganj and Chapra. No sample was found to exceed the allowable limits suggested by WHO. The occurrence of high chloride, nitrate, and mostly bicarbonate ions concentrations in the groundwater of the study area and their dependence on each other can increase uranium concentration in the future. Fluoride concentrations are found within allowable values suggested for drinking purposes. Cancer is possible as the mean C.R value of As and U increases.

Recently, the Nigeria Centre for Disease Control in Bauchi she ate has reported yellow fever. Jagaba et al. (2020) stated that water resource research is insufficient for mitigating measures. The evaluation of water quality in the Rafin Zurfi area, Bauchi state, from hand-dug wells was done by Water Quality Index (WQI), Target Hazard Quotient (THQ) and Hazard Index (HI). The standard methods of the American Public Health Association (APHA) were used to examine the water quality of hand-dug wells. The study outcomes showed that according to NSDWQ, the pH values of the collected sample are within acceptable limits. In contrast, samples E and L exceeded the World Health Organization's allowable limits. Turbidity, TH, BOD, TSS, EC, Cu, Zn, Ca, SO42- and Cl values were within acceptable limits.

Arjun Ram et al. (2021) assessed the groundwater quality of District Mahoba, Uttar Pradesh, India. The collected samples were tested for various physical and chemical characteristics, and the WQI model was applied to determine the overall quality of water. In the study area, the overall WQI depicts that the groundwater is potable and safe, except for a few points in the Jaitpur and Charkhari Blocks.

Palwasha Akram et al. (2020) the groundwater quality of 9 cities and industrial cities in Sindh, Pakistan was studied, and physical and chemical parameters and methods (WQI) were determined. The WQI model concluded that the three towns with WQI values of 28.9, 49.8, and 50 belong to the category of high-quality water. Three samples showed typical WQI values, namely 55.8, 60.9 and 72.7, and good water quality. Since the water quality index of the other three cities is very high, namely 100.6, 106.6, and 164.2, pollution was found in the water samples of the other three cities. Therefore, the water is considered unsafe for drinking and commercial use.

Solangi et al. (2019a) assessed the groundwater quality in Thatta district, Sindh, Pakistan, using the concentrations of groundwater with various physicochemical properties. Also, the concentrators were mapped spatially using the ArcGIS spatial interpolation techniques. WQI models were also used to evaluate the study area's water quality. To conclude, the research discovered that the study's water is contaminated and needs to be addressed. Therefore, WQI, models and GIS tools help evaluate and delineate groundwater quality.

Solangi et al. (2018) applied two types of WQI indices to observe the overall quality of surface water in the deltaic area of Pakistan. The water quality data were also analyzed statistically using the IBM SPSS software package. Overall, the study found that surface water in most deltas is severely polluted. Furthermore, the study found WQIs valuable tools for assessing the overall quality of water resources.

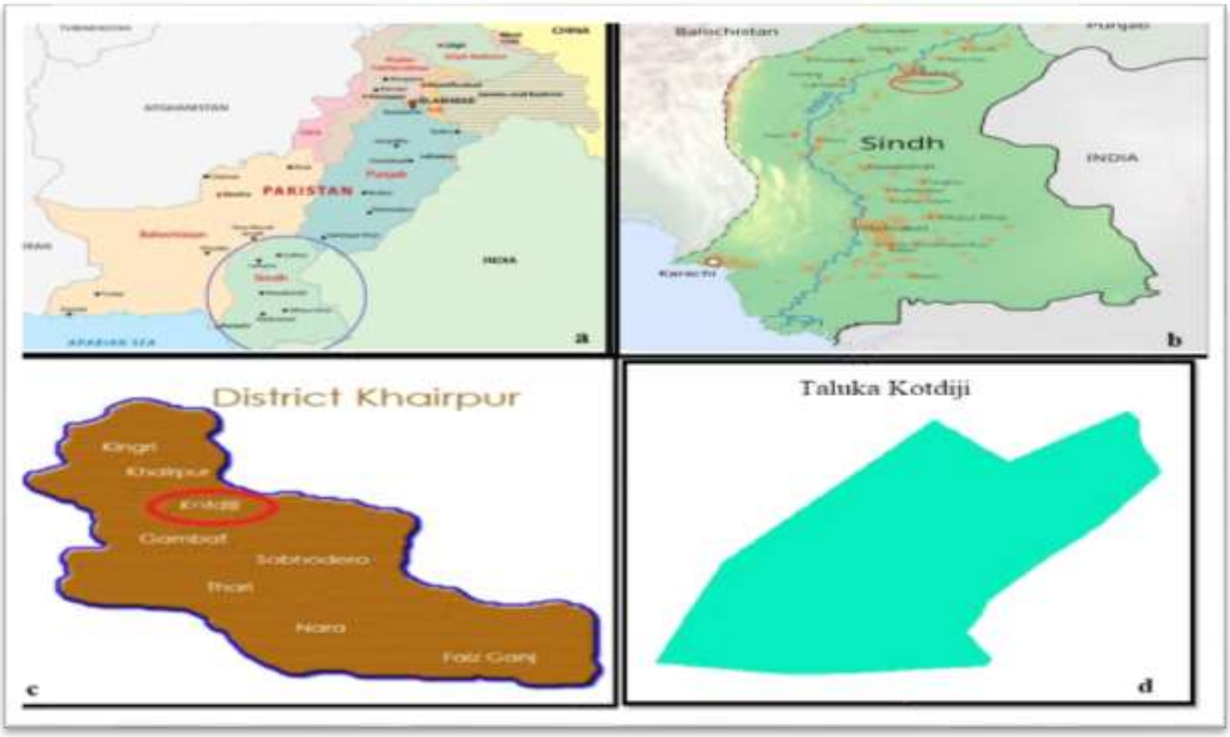
## Materials and Methods

### The Study Area (Taluka Kotdiji)

This study has been carried out to assess and outline the suitability of groundwater for domestic and irrigation usage in the Taluka Kotdiji. Figures 1a, b, c and d show the Google maps of Pakistan, Sindh, Khairpur Mirs and Kotdiji, respectively. Administratively, Taluka Kotdiji is a sub-district of District Khairpur. District Khairpur is one of the biggest districts of Northern Sindh, Pakistan. The research zone encompasses between latitude and longitude of 27°20′44″N to 68°42′24″E. The total population of the study area is almost 3 48,899. The weather is too hot and too cold in summer and winter respectively. The region collects a small amount of rainfall, about 10 cm.

The Rabi and Kharif are two major cropping seasons. The major crops to be grown in the research area are wheat, barley, cotton, sugarcane, rice, and vegetables. Moreover, the area is also popular for the tillage of date palms (Khajoor) around the country. Most of the people in the study area are educated. However, some of the area's people depend on agriculture to earn bread and butter. The study area is situated on the left bank of the Indus River. The region's inhabitants extensively use groundwater for drinking and irrigation due to the scarcity of fresh water in the canals off-taking from Sukkur Barrage and a minor yearly rainfall. This valuable region asset is being polluted due to climate change, low recharging rates, and the use of agrochemicals. Hence, the present study has been carried out to assess and delineate the quality of this natural resource in the area.

**Figure: 1 a, b, c & d: Google maps of Pakistan, Sindh, Khairpur Mir's & Kotdiji**




## Water Sampling

For this study, thirty-nine (39) geo-referenced groundwater samples were collected from Thirteen (13) different Union Councils of Taluka Kotdiji as mentioned in Table 1. Water samples were gathered from tube wells, hand pumps and electric motors fixed in the most populated villages of each Union Council. The samples were taken in one-litre plastic bottles using all the available standards. While site coordinates were recorded using handheld Garmin 62s GPS (Solangi et al. 2019a, b).

**Table 1: Description of Sampled Groundwater Locations**

| S. No. | Location | Source | Depth of Groundwater Sample (ft) | Union Council |
|---|---|---|---|---|
| 1 | Village Qadir Bux Keerio | EM | 35-40 | Talpur Wada |
| 2 | Babar Wada | HP | 35-40 | |
| 3 | Talpur Wada | TW | 80-90 | |
| 4 | Bagodaro | EM | 25-30 | Naseer Faqir Jalalni |
| 5 | Noor Bozdar | TW | 65-75 | |
| 6 | Nasir Faqir Jalalni | EM | 25-30 | |
| 7 | Nangreja | HP | 35-40 | Ali Muhammad Machhi |
| 8 | Koral Shah | TW | 60-70 | |
| 9 | M. Bux Khaskheli | EM | 35-40 | |

| | | | | |
|---|---|---|---|---|
| 10 | Raheem Bux Wasasn | HP | 45-50 | Jhando Mashaikh |
| 11 | Gul Muhammad Jamro | TW | 80-90 | |
| 12 | Mulko Wauhan | HP | 50-55 | |
| 13 | Sohu Kanasrah | HP | 55-60 | Atta Muhammad Hami |
| 14 | Baharo Lashari | HP | 40-45 | |
| 15 | Bakhu Khan Lashari | HP | 45-50 | |
| 16 | Naro Dhoro | HP | 55-60 | Muhabat Wah |
| 17 | Bakhar Kanasrah | EM | 55-60 | |
| 18 | Sono Gopang | TW | 100-110 | |
| 19 | Chodaho | HP | 50-55 | Fateh Pur |
| 20 | DhupWaro | EM | 65-70 | |
| 21 | Daro Mahar | EM | 50-55 | |
| 22 | Ahmed Abad Bari | HP | 25-30 | Bafo |
| 23 | Nebaho Pato | TW | 75-85 | |
| 24 | Bangul Khan Chandio | EM | 25-30 | |
| 25 | Jiskani | EM | 25-30 | Jiskani |
| 26 | Adam Ujan | HP | 20-25 | |
| 27 | Naseer Khan Chakrani | TW | 70-80 | |
| 28 | Nawab Wassan | EM | 30-35 | Raheem Bux Wassan |
| 29 | Qaim Khan Gopang | HP | 20-25 | |
| 30 | Heesbani | HP | 25-30 | |
| 31 | Gondhiro | HP | 30-35 | Gondhiro |
| 32 | Kotlo | TW | 80-90 | |
| 33 | Rajpari | HP | 35-40 | |
| 34 | Layari | HP | 35-40 | Layari |
| 35 | Hussain Abad | EM | 40-45 | |
| 36 | Raban Rajper | TW | 75-85 | |
| 37 | Deh Sohu | HP | 35-40 | Deh Sohu |
| 38 | Mithri | EM | 30-35 | |
| 39 | Mithan faqir | HP | 40-45 | |

HP: Hand Pump
EM: Electric Motor
TW: Tube Well

**Physicochemical Analysis**

By using available standard laboratory and field methods, groundwater samples were analyzed for taste, color, odor, turbidity, pH, TDS, EC, Cl, Ca, Mg and TH.

**Table 2: Water Quality Parameters and Methods adopted for Analysis**

| Parameters | Test method |
|---|---|
| Color (TCU) | Sensory Test |
| Odor | Sensory Test |
| Taste (bitter, salty, sour and sweet) | Sensory Test |
| Turbidity (NTU) | Turbidity Meter, Lamotte, Model 2008, USA |
| Calcium (mg/l) | 3500-Ca-D, Standard method (1992) |
| Chlorides (mg/l) | Titration, Standard Method (1992) |
| Hardness (mg/l) | EDTA Titration, Standard Method (1992) |
| Magnesium (mg/l) | 2340-C, Standard Method (1992) |
| pH at 25°C | pH Meter, Hanna Instrument, Model 8519, Italy |
| TDS (mg/l) | TDS meter |

### Analysis Based on WQI Model

Quality of groundwater was examined by applying WQI model on the basis of laboratory results of various physicochemical parameters as mentioned above. The WQI model is a mathematical tool which is extensively applied all around the world by several scholars (Shabbir & Ahmad 2015; Sener et al., 2017; Solangi et al., 2018; Solangi et al., 2019a, b) for judging the overall appropriateness of groundwater and surface water for drinking purpose. The model is calculated using three steps as stated in Steps 1-3.

**Step 1**

Determination of relative weight ($W_i$) of the ith parameter using the expression stated as:

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i}$$

Where $w_i$is the assigned weight to each of the *ith* water quality parameters.

**Step 2**

Calculation of rating scale ($Qi$):

$$Q_i = \frac{C_o}{C_p} \times 100$$

Where $C_o$ is the observed concentration and $C_p$ is the allowable limit suggested by WHO for domestic use.

**Step 3**

Calculation of WQI:

$$WQI = \sum W_i \text{ x } Q_i$$

Using this expression, the overall suitability of water in the study area has been determined. Based on the calculated WQI, if WQI, <50, water is considered as excellent water, >50-100 as good water, >100-200 as poor water, >200-300 as very poor and exceeding 300 as unfit for drinking purposes (Shabbir & Ahmad, 2015; Solangi et al. 2019a, b).

### Spatial Distribution Maps for Various Parameters

Based on the observed concentrations of various physical and chemical parameters in the collected groundwater samples, GIS maps to indicate the spatial changes in groundwater quality were developed using ArcGIS 10.5 software (Solangi et al., 2019a, b).

## Results and Discussion

### Analysis of Physical and Chemical Parameters of Groundwater

Table 3 describes the laboratory results of different physicochemical parameters EC, Ca, Mg, TH, Chloride, pH, Turbidity, and TDS of groundwater samples collected from the study area. Whereas table 3 shows the permissible, maximum, minimum and mean values of analyzed groundwater samples collected from various locations in the study area.

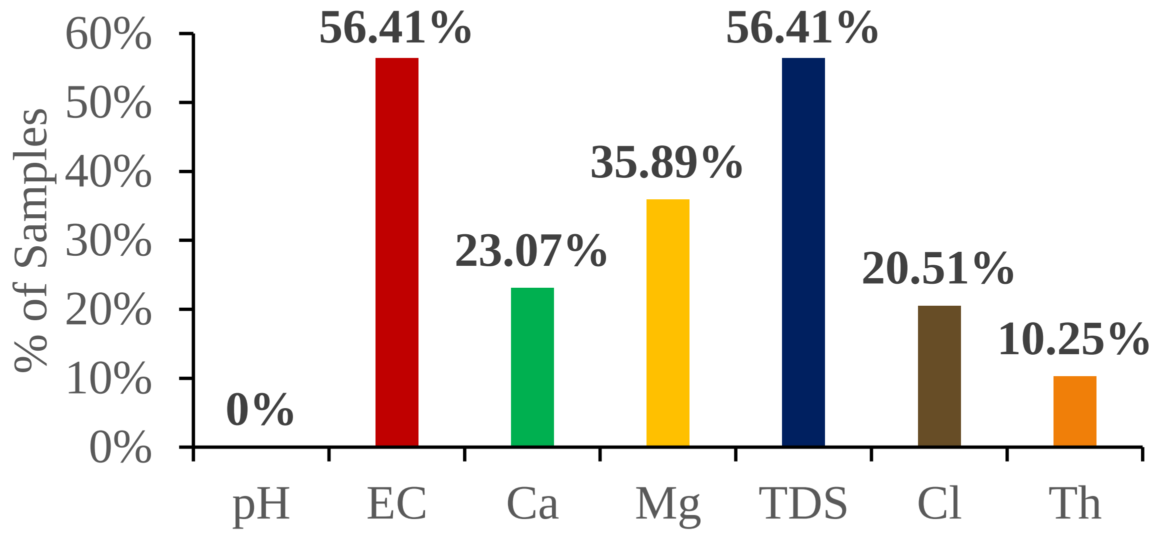
**Table 3: Results of Physicochemical Parameters**

| Area Code | pH | Turbidity (NTU) | EC (dS/m) | Ca (mg/L) | Mg (mg/L) | Cl (mg/L) | TH (mg/L) | TDS (mg/L) |
|---|---|---|---|---|---|---|---|---|
| A-1 | 7.5 | 0.0 | 0.6 | 41.3 | 49.2 | 92.0 | 100.0 | 371.5 |
| A-2 | 7.3 | 0.0 | 0.6 | 49.9 | 45.9 | 80.0 | 90.0 | 397.3 |
| A-3 | 7.1 | 0.0 | 1.3 | 56.8 | 37.9 | 88.0 | 90.0 | 844.9 |
| A-4 | 7.6 | 0.0 | 1.8 | 123.7 | 60.0 | 392.0 | 440.0 | 1152.1 |
| A-5 | 7.5 | 0.0 | 0.6 | 46.0 | 48.9 | 64.0 | 70.0 | 377.6 |
| A-6 | 7.8 | 0.0 | 1.0 | 65.5 | 41.9 | 192.0 | 200.0 | 661.8 |
| A-7 | 7.2 | 1.0 | 2.0 | 103.6 | 208.9 | 72.0 | 80.0 | 1248.1 |
| A-8 | 7.5 | 0.0 | 1.2 | 60.5 | 55.6 | 16.0 | 30.0 | 786.4 |
| A-9 | 7.5 | 0.0 | 1.0 | 66.0 | 51.9 | 192.0 | 200.0 | 637.0 |
| A-10 | 7.3 | 0.0 | 0.5 | 55.8 | 100.6 | 80.0 | 90.0 | 326.7 |
| A-11 | 7.5 | 1.0 | 0.4 | 45.3 | 62.9 | 132.0 | 140.0 | 282.0 |
| A-12 | 7.5 | 0.0 | 1.1 | 56.9 | 57.9 | 124.0 | 140.0 | 680.1 |
| A-13 | 7.2 | 0.0 | 1.0 | 11.7 | 37.9 | 40.0 | 60.0 | 652.9 |
| A-14 | 7.5 | 0.0 | 0.5 | 85.2 | 5.5 | 88.0 | 90.0 | 341.8 |
| A-15 | 7.6 | 0.0 | 3.3 | 50.1 | 32.9 | 1208.0 | 1640.0 | 2115.4 |
| A-16 | 7.5 | 0.0 | 0.5 | 48.9 | 49.0 | 48.0 | 60.0 | 301.1 |
| A-17 | 7.5 | 0.0 | 0.5 | 39.7 | 11.4 | 84.0 | 90.0 | 333.4 |
| A-18 | 7.7 | 0.0 | 0.4 | 96.7 | 56.9 | 204.0 | 240.0 | 275.3 |
| A-19 | 7.5 | 0.0 | 1.6 | 25.2 | 32.9 | 328.0 | 360.0 | 1050.9 |
| A-20 | 7.4 | 0.0 | 2.7 | 38.2 | 47.6 | 1468.0 | 1180.0 | 1706.7 |
| A-21 | 7.5 | 0.0 | 0.5 | 48.9 | 82.5 | 1928.0 | 1240.0 | 313.9 |
| A-22 | 7.5 | 1.0 | 1.2 | 68.5 | 35.7 | 88.0 | 90.0 | 739.0 |
| A-23 | 7.2 | 0.0 | 1.0 | 85.8 | 52.9 | 525.0 | 380.0 | 637.2 |
| A-24 | 7.5 | 0.0 | 0.9 | 62.9 | 43.6 | 144.0 | 160.0 | 563.5 |
| A-25 | 7.6 | 0.0 | 1.2 | 90.6 | 62.9 | 200.0 | 240.0 | 755.6 |
| A-26 | 7.5 | 0.0 | 0.7 | 134.0 | 47.9 | 28.0 | 30.0 | 432.1 |
| A-27 | 7.5 | 1.0 | 0.4 | 51.6 | 92.5 | 20.0 | 30.0 | 270.7 |
| A-28 | 7.4 | 0.0 | 0.5 | 66.9 | 30.6 | 172.0 | 180.0 | 340.6 |
| A-29 | 7.1 | 0.0 | 0.9 | 45.0 | 24.9 | 232.0 | 260.0 | 585.4 |
| A-30 | 7.5 | 0.0 | 1.4 | 57.6 | 45.4 | 56.0 | 60.0 | 900.9 |
| A-31 | 7.5 | 0.0 | 0.9 | 70.6 | 58.7 | 260.0 | 280.0 | 570.0 |
| A-32 | 7.5 | 0.0 | 0.3 | 130.9 | 31.9 | 20.0 | 300.0 | 179.7 |
| A-33 | 7.3 | 0.0 | 0.5 | 58.8 | 49.6 | 48.0 | 60.0 | 295.7 |
| A-34 | 7.5 | 0.0 | 0.4 | 65.9 | 36.9 | 28.0 | 30.0 | 238.9 |
| A-35 | 7.6 | 0.0 | 0.4 | 48.5 | 47.6 | 40.0 | 60.0 | 283.4 |
| A-36 | 7.5 | 1.0 | 0.6 | 69.6 | 85.0 | 80.0 | 100.0 | 354.5 |
| A-37 | 7.5 | 1.0 | 1.9 | 112.4 | 42.6 | 464.0 | 560.0 | 1225.4 |
| A-38 | 7.4 | 0.0 | 0.8 | 71.6 | 46.8 | 172.0 | 180.0 | 506.1 |
| A-39 | 7.1 | 0.0 | 0.8 | 53.9 | 29.0 | 140.0 | 160.0 | 533.8 |

**Table 4: Summary of Groundwater Quality Parameters Analysis Results**

| Parameter | EC (dS/m) | T (NTU) | Ca (mg/L) | Cl (mg/L) | TH (mg/L) | Mg (mg/L) | pH | TDS (mg/L) |
|---|---|---|---|---|---|---|---|---|
| **Permissible** | 0.75 | 5 | 75 | 250 | 500 | 50 | 8.5 | 500 |
| **Maximum** | 3.31 | 1 | 133.9 | 1928 | 1640 | 208.9 | 7.8 | 2115.39 |
| **Minimum** | 0.28 | 0 | 5 | 16 | 30 | 5.5 | 7.1 | 179.65 |
| **Mean** | 0.96 | 0.15 | 64.59 | 247.1 | 251 | 51.1 | 7.5 | 622.3 |

**Figure 2: Physicochemical Analysis of groundwater samples**




No any sample has crossed the WHO pH limits, 56.41% of samples in EC, 10.25% of samples in TH, 56.41% of samples in TDS, 23.07% of samples in Ca, 35.89% of samples in Mg and 20.51% of samples in Cl had values above permissible limits

Based on the sensory test, most of the analyzed groundwater samples were found free from odor, color, etc. Also, no change in the taste of the samples was observed. According to WHO, the pH value of drinking water should be in the range of 6.5 to 8.5. However, the minimum, maximum and mean values of pH in the groundwater of the study area were obtained as 7.1, 7.8 and 7.45 respectively. Figure 3a shows the spatial distribution of pH in the groundwater of the study area.

The WHO recommended value for the turbidity of drinking water is 5 NTU (Nephelometric Turbidity Unit). The observed minimum, maximum and mean values of Turbidity were respectively 0, 1 and 0.15 NTU. Figure 3b shows the spatial distribution of turbidity in the groundwater of the study area.

Calcium provides temporary hardness in water. According to WHO, the soft and suitable water for drinking purposes should not exceed recommended limit of 75 mg/l of hardness The analyzed samples showed the minimum, maximum and mean values of Calcium as 5 mg/L, 133.9 mg/L and 64.59 mg/L. Results revealed that areas A-4, A-7, A-14, A-18, A-23, A-25, A-26, A-32 and A-37 have values of Calcium (temporary hardness) beyond the standard limit. Thus, the groundwater of these areas of taluka Kotdiji is unsafe for drinking purposes. The groundwater quality of the remaining areas is safe for drinking purposes. Magnesium is responsible for providing permanent hardness in water. The suggested value of magnesium as per WHO for drinking water is 50 mg/l. The minimum, maximum and mean values of Magnesium in the study area were determined as 5.5 mg/L, 208.9 mg/L and 51.1 mg/L. Areas A-4, A-7, A-8, A-9, A-10, A-11, A-12, A-18, A-21, A-23, A-25, A-27, A-31 and A-36 have crossed the target line of 50 mg/l. The groundwater quality of these areas of taluka Kotdiji is vulnerable to use for drinking purposes. The remaining areas have a safe limit of magnesium to use for drinking. **Fig. 3c** shows that some areas of the study area on the Eastern and Southern sides have a calcium range beyond the limits. It is clear from the interpolation map (Figure. 3d) that the Eastern and South-Western areas of the study area have a magnesium range beyond the specified limit suggested by WHO (2011).

Hardness causes more soap consumption for cleaning and washing clothes. Total hardness includes temporary hardness (calcium) and permanent hardness (magnesium). The minimum, maximum and mean values of total hardness were found as 30 mg/L, 1640 mg/L and 251 mg/L respectively. Analysis revealed that only four locations i.e. A-15, A-20, A-21, and A-37 have crossed the target line. The remaining locations of taluka Kotdiji have total hardness within the safe limit i.e., lower than the recommended value of 500mg/l. The colors of a thematic map (Figure. 3e) show that most areas have TH concentration within WHO limits. However, few South-Eastern and Western areas have total hardness concentration beyond the suggested limits.

WHO has suggested the permissible level of chlorides in drinking water as 250 mg/l. The obtained minimum, maximum and mean values of Chlorides in the study area are 16 mg/L, 1928 mg/L and 247.1 mg/L respectively. Groundwater collected locations A-4, A-15, A-19, A-20, A-21, A-23, A-31 and A-37 have chloride concentration more than specified limits. Other areas of taluka Kotdiji fall within acceptable limits of chloride. In a GIS map (Figure 3f), the light green, red and yellow colors in the South-East of the study area show that the water quality of these areas is vulnerable in terms of chloride.

World Health Organization has suggested a maximum limit of 0.75 dS/m of EC for safe drinking water. The minimum value of EC was found as 0.28 dS/m, the maximum 3.31 dS/m and the mean value was 0.96 dS/m. Analysis revealed that 22 samples out of 39 have crossed the recommended value of 0.75 dS/m. According to these results, the groundwater quality of taluka Kotdiji is not suitable for drinking purposes in terms of EC. Figure 4a shows that groundwater quality in most of the locations of the study area is not safe in terms of EC.

TDS describes the number of anions and cations present in water. Suitable water should not have some TDS of more than 500 mg/l as prescribed by World Health Organization (WHO). The calculated minimum, maximum and mean values of total dissolved solids in the study area were 179.65 mg/L, 2115.39 mg/L and 622.3 mg/L respectively. As per analysis, 21 areas have crossed the recommended value of 500 mg/l. It means 56% of samples have unsafe water quality for drinking use. The groundwater quality of taluka Kotdiji is not safe in terms of TDS. GIS maps of TDS (Figure 4b). shows that the areas lying on the eastern and western sides of the study areas have a serious threat in terms of water quality.

**Figure 3: GIS map of pH (a), Turbidity (b), Ca (c), Mg (d), TH (e), and Cl (f)**

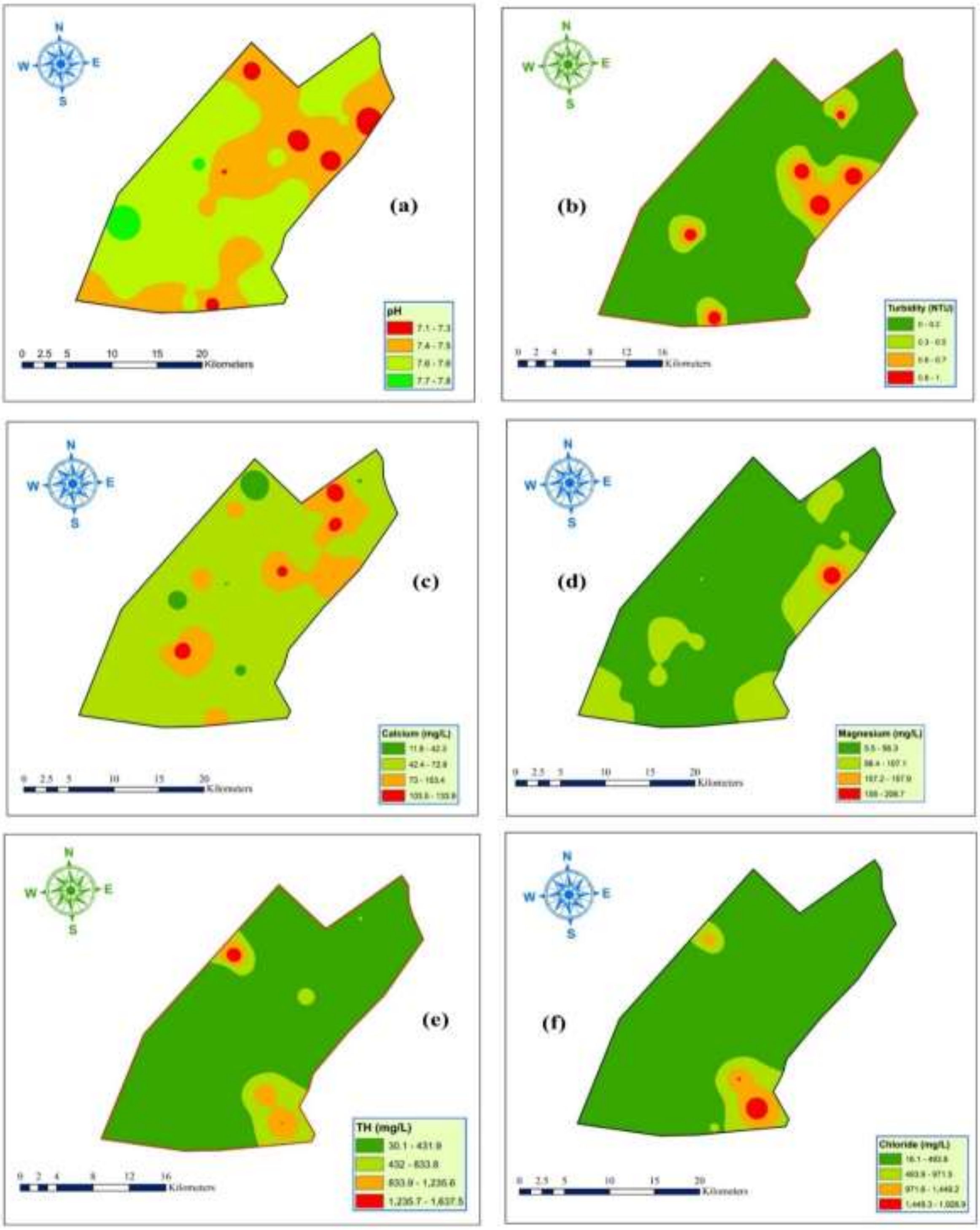
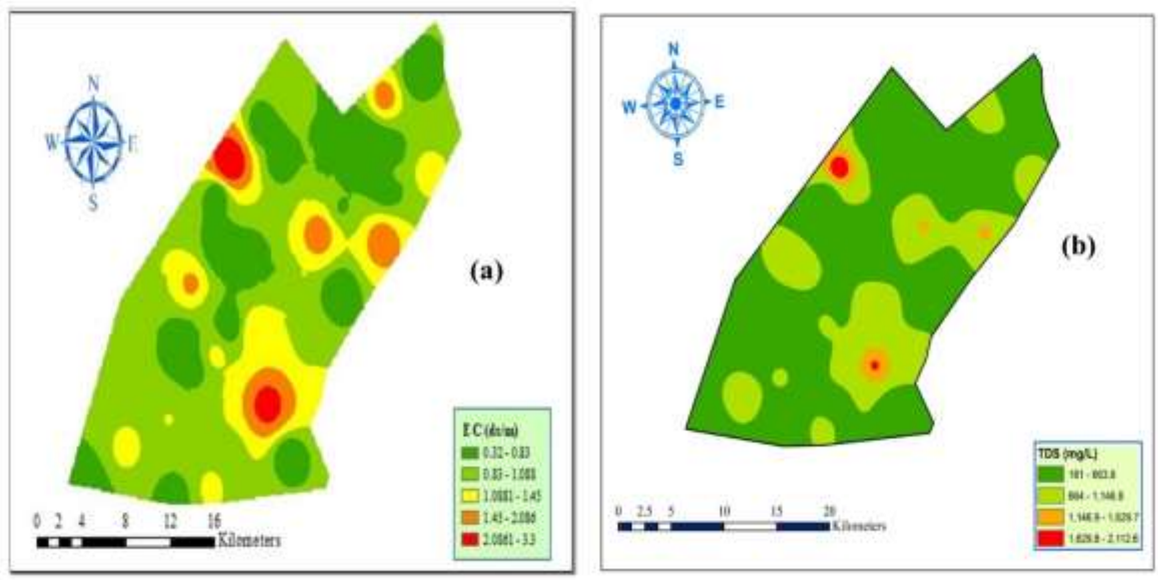


**Figure 4: GIS map of EC (a) and TDS (b)**




## Groundwater Quality Based on the Applied WQI Model

Based on the analysis results of different physicochemical properties as described above, the quality of the groundwater for domestic purposes was analyzed using the WQI model. The model is calculated using three steps as stated earlier. To determine the values of the WQI model for each analyzed water sample, assigned weights and relative weights to each physicochemical parameter are given in table 5.

**Table 5: Calculation of Assigned weights, and Relative weight (Wi)**

| Parameter | Assigned Weight (wi) | Relative Weight (Wi) |
|---|---|---|
| pH | 3 | 0.14 |
| Chloride | 4 | 0.18 |
| Calcium | 2 | 0.09 |
| Total Dissolved Solids | 4 | 0.18 |
| Total Hardness | 3 | 0.14 |
| Electrical Conductivity | 4 | 0.18 |
| Magnesium | 2 | 0.09 |

However, calculated values of rating scale (Qi) for determination of WQI are described in table 6.

**Table 6: Results of Scale Rating (Qi)**

| pH | Cl | Ca | TDS | TH | EC | Mg |
|---|---|---|---|---|---|---|
| 107.143 | 36.800 | 55.011 | 48.000 | 20.000 | 82.929 | 65.590 |
| 104.286 | 32.000 | 66.476 | 46.000 | 18.000 | 88.686 | 61.195 |
| 101.429 | 35.200 | 75.714 | 84.000 | 18.000 | 188.600 | 50.473 |
| 108.571 | 156.800 | 164.900 | 132.000 | 88.000 | 257.171 | 79.986 |
| 107.143 | 25.600 | 61.314 | 52.000 | 14.000 | 84.286 | 65.195 |
| 111.429 | 76.800 | 87.269 | 72.000 | 40.000 | 147.714 | 55.810 |
| 102.857 | 28.800 | 138.098 | 412.000 | 16.000 | 278.600 | 278.569 |
| 107.143 | 6.400 | 80.650 | 52.000 | 6.000 | 175.529 | 74.119 |
| 107.143 | 76.800 | 87.983 | 49.000 | 40.000 | 142.186 | 69.143 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 104.286 | 32.000 | 74.376 | 98.000 | 18.000 | 72.914 | 134.161 |
| 107.143 | 52.800 | 60.343 | 62.000 | 28.000 | 62.943 | 83.862 |
| 107.143 | 49.600 | 75.794 | 64.000 | 28.000 | 151.814 | 77.143 |
| 102.857 | 16.000 | 15.550 | 56.000 | 12.000 | 145.743 | 50.479 |
| 107.143 | 35.200 | 113.545 | 53.000 | 18.000 | 76.286 | 7.305 |
| 108.571 | 483.200 | 66.834 | 65.000 | 328.000 | 472.186 | 43.802 |
| 107.143 | 19.200 | 65.194 | 24.000 | 12.000 | 67.214 | 65.291 |
| 107.143 | 33.600 | 52.957 | 96.000 | 18.000 | 74.414 | 15.221 |
| 110.000 | 81.600 | 128.872 | 24.000 | 48.000 | 61.443 | 75.805 |
| 107.143 | 131.200 | 33.527 | 64.000 | 72.000 | 234.571 | 43.858 |
| 105.714 | 587.200 | 50.961 | 260.000 | 236.000 | 380.957 | 63.417 |
| 107.143 | 771.200 | 65.188 | 416.000 | 248.000 | 70.071 | 110.032 |
| 107.143 | 35.200 | 91.261 | 104.000 | 18.000 | 164.957 | 47.576 |
| 102.857 | 210.000 | 114.385 | 140.000 | 76.000 | 142.229 | 70.529 |
| 107.143 | 57.600 | 83.810 | 96.000 | 32.000 | 125.786 | 58.089 |
| 108.571 | 80.000 | 120.760 | 29.000 | 48.000 | 168.657 | 83.812 |
| 107.143 | 11.200 | 178.647 | 68.000 | 6.000 | 96.457 | 63.856 |
| 107.143 | 8.000 | 68.834 | 84.000 | 6.000 | 60.414 | 123.306 |
| 105.714 | 68.800 | 89.143 | 96.000 | 36.000 | 76.029 | 40.785 |
| 101.429 | 92.800 | 59.949 | 120.000 | 52.000 | 130.671 | 33.138 |
| 107.143 | 22.400 | 76.851 | 84.000 | 12.000 | 201.100 | 60.493 |
| 107.143 | 104.000 | 94.120 | 96.000 | 56.000 | 127.229 | 78.234 |
| 107.143 | 8.000 | 174.477 | 68.000 | 60.000 | 40.100 | 42.479 |
| 104.286 | 19.200 | 78.327 | 34.000 | 12.000 | 66.000 | 66.099 |
| 107.143 | 11.200 | 87.810 | 49.000 | 6.000 | 53.329 | 49.145 |
| 108.571 | 16.000 | 64.723 | 54.000 | 12.000 | 63.257 | 63.426 |
| 107.143 | 32.000 | 92.843 | 38.000 | 20.000 | 79.129 | 113.368 |
| 107.143 | 185.600 | 149.826 | 176.000 | 112.000 | 273.529 | 56.788 |
| 105.714 | 68.800 | 95.453 | 120.000 | 36.000 | 112.971 | 62.439 |
| 101.429 | 56.000 | 71.808 | 96.000 | 32.000 | 119.143 | 38.610 |

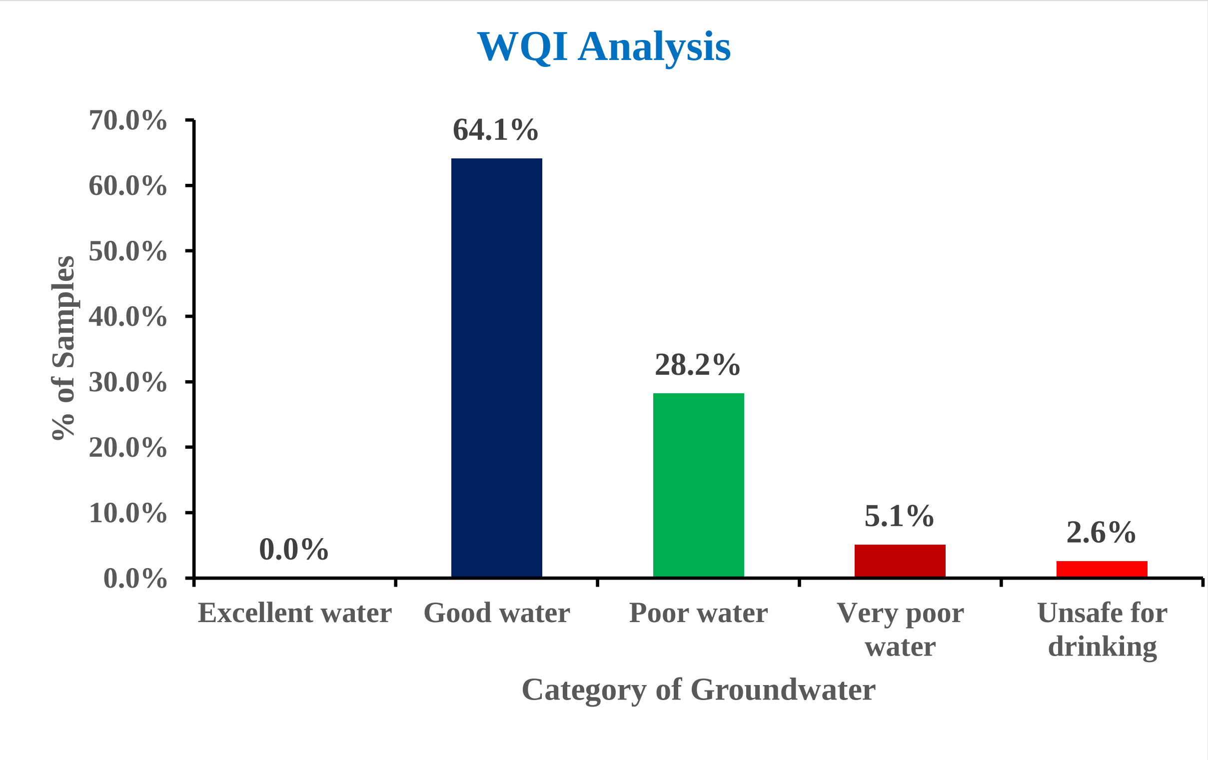
Finally, the WQI values for each groundwater sample are described in table 7.

**Table 7: Results of the WQI Model**

| Area | Location Name | Longitude | Latitude | WQI = $\sum$ Wi*qi | Category of water |
|---|---|---|---|---|---|
| A-1 | Village Qadir Bux Keerio | 68.816 | 27.482 | 61.80 | **Good water** |
| A-2 | Babar Wada | 68.621784 | 27.241589 | 61.37 | **Good water** |
| A-3 | Talpur Wada | 68.825 | 27.427 | 85.75 | **Good water** |
| A-4 | Bagodaro | 68.792 | 27.47 | 151.43 | **Poor water** |
| A-5 | Noor Bozdar | 68.707 | 27.434 | 60.42 | **Good water** |
| A-6 | Nasir Faqir Jalalni | 68.586 | 27.325 | 89.96 | **Good water** |
| A-7 | Nangreja | 68.79 | 27.388 | 196.17 | **Poor water** |
| A-8 | Koral Shah | 68.582968 | 27.269039 | 75.21 | **Good water** |
| A-9 | M. Bux Khaskheli | 68.73 | 27.33 | 86.09 | **Good water** |
| A-10 | Raheem Bux Wasasn | 68.550149 | 27.247306 | 78.45 | **Good water** |
| A-11 | Gul Muhammad Jamro | 68.756 | 27.358 | 67.67 | **Good water** |
| A-12 | Mulko Wauhan | 68.617 | 27.286 | 83.93 | **Good water** |
| A-13 | Sohu Kanasrah | 68.711345 | 27.474718 | 63.49 | **Good water** |
| A-14 | Baharo Lashari | 68.692399 | 27.453374 | 58.33 | **Good water** |

| | | | | | |
|---|---|---|---|---|---|
| A-15 | Bakhu Khan Lashari | 68.667078 | 27.433016 | 256.72 | **Very Poor Water** |
| A-16 | Naro Dhoro | 68.656341 | 27.414069 | 51.24 | **Good water** |
| A-17 | Bakhar Kanasrah | 68.683326 | 27.378995 | 61.06 | **Good water** |
| A-18 | Sono Gopang | 68.659581 | 27.383731 | 74.02 | **Good water** |
| A-19 | Chodaho | 68.635308 | 27.36322 | 111.38 | **Poor water** |
| A-20 | DhupWaro | 68.697 | 27.294 | 282.06 | **Very Poor Water** |
| A-21 | Daro Mahar | 68.714 | 27.265 | 296.75 | **Very Poor Water** |
| A-22 | Ahmed Abad Bari | 68.652247 | 27.246181 | 86.90 | **Good water** |
| A-23 | Nebaho Pato | 68.671369 | 27.245785 | 133.46 | **Poor water** |
| A-24 | Bangul Khan Chandio | 68.666731 | 27.266612 | 85.15 | **Good water** |
| A-25 | Jiskani | 68.65532 | 27.322824 | 94.08 | **Good water** |
| A-26 | Adam Ujan | 68.638925 | 27.314266 | 72.16 | **Good water** |
| A-27 | Naseer Khan Chakrani | 68.628302 | 27.328191 | 66.12 | **Good water** |
| A-28 | Nawab Wassan | 68.6663517 | 27.339516 | 76.72 | **Good water** |
| A-29 | Qaim Khan Gopang | 68.683639 | 27.378039 | 93.17 | **Good water** |
| A-30 | Heesbani | 68.68662 | 27.337251 | 87.11 | **Good water** |
| A-31 | Gondharo | 68.802815 | 27.426541 | 100.77 | **Poor water** |
| A-32 | Kotlo | 68.791323 | 27.438174 | 65.74 | **Good water** |
| A-33 | Rajpari | 68.794392 | 27.418615 | 53.71 | **Good water** |
| A-34 | Layari | 68.770085 | 27.440047 | 50.81 | **Good water** |
| A-35 | Hussain Abad | 68.777165 | 27.446877 | 55.25 | **Good water** |
| A-36 | Raban Rajper | 68.777165 | 27.446877 | 68.30 | **Good water** |
| A-37 | Deh Sohu | 68.738965 | 27.392329 | 166.15 | **Poor water** |
| A-38 | Mithri | 68.742357 | 27.451166 | 91.18 | **Good water** |
| A-39 | Mithan faqir | 68.757416 | 27.40726 | 79.16 | **Good water** |

**Figure 5: Categories of Groundwater based on the WQI Model**



The graphical representation of the Water Quality Index (WQI) model (figure 5) depicts that no sample was of excellent quality. However, 64.1% of samples were in a good category, 28.2% in the poor category, 5.1% samples in the very poor category and 2.6% of the groundwater samples were not fit for drinking purposes.

## Conclusion

The sensory test of Taste, Color and Odor showed that all collected samples of the study area were tasteless, colorless and odorless. However, 56.41%, 23.07%, 35.89%, 20.51%, 10.26% and 56.41% of the samples had EC, Ca, Mg, TH and TDS concentrations beyond the WHO guidelines. Analysis based on the WQI model, no water sample was in the excellent category, however, 64.1%, 28.2%, 5.1% and 2.6% of the samples fall in good, poor, very poor and unsuitable for drinking categories. The GIS maps depicted that water quality on the South-Eastern side of the study area is vulnerable in terms of chlorides and total hardness. Overall, the study revealed that the quality of water in many areas of taluka Kotdiji is not as per WHO guidelines. It should be treated well before being used for drinking. A campaign should be carried out to aware people of the bad quality of water and its effects on health.

## References


- Adimalla, N., & Li, P. (2019). Occurrence, health risks, and geochemical mechanisms of fluoride and nitrate in groundwater of the rock-dominant semi-arid region, Telangana State, India. *Human and Ecological Risk Assessment: An International Journal*, *25*(1-2), 81-103.
- Adimalla, N., Dhakate, R., Kasarla, A., & Taloor, A. K. (2020). Appraisal of groundwater quality for drinking and irrigation purposes in Central Telangana, India. *Groundwater for Sustainable Development*, *10*, 100334.
- Akram, P., Solangi, G. S., Shehzad, F. R., & Ahmed, A. (2020). Groundwater Quality Assessment using a Water Quality Index (WQI) in Nine Major Cities of Sindh, Pakistan. *International Journal of Research in Environmental Science (IJRES)*, 6(3), 18-26.
- Asghari, F. B., Jaafari, J., Yousefi, M., Mohammadi, A. A., & Dehghanzadeh, R. (2018). Evaluation of water corrosion, scaling extent and heterotrophic plate count bacteria in asbestos and polyethylene pipes in drinking water distribution system. *Human and Ecological Risk Assessment: An International Journal*, *24*(4), 1138-1149.
- Azizullah A, Khattak MNK, Richter P, Hader DP (2011) Water pollution in Pakistan and its impact on public health, a review. *Environment Int* 37(2), 479-497.
- Carasek, F. L., Baldissera, R., Oliveira, J. V., Scheibe, L. F., & Dal Magro, J. (2020). Quality of the groundwater of the Serra Geral Aquifer System of Santa Catarina west region, Brazil. *Groundwater for Sustainable Development*, *10*, 100346.
- Das, A., Das, S. S., Chowdhury, N. R., Joardar, M., Ghosh, B., & Roychowdhury, T. (2020). Quality and health risk evaluation for groundwater in Nadia district, West Bengal: An approach on its suitability for drinking and domestic purpose. *Groundwater for Sustainable Development*, *10*, 100351.
- El-Rawy, M., Wahba, M., Fathi, H., Alshehri, F., Abdalla, F., & El Attar, R. M. (2024). Assessment of groundwater quality in arid regions utilizing principal component analysis, GIS, and machine learning techniques. *Marine Pollution Bulletin*, *205*, 116645.
- Forstinus, N. O., Ikechukwu, N. E., Emenike, M. P., & Christiana, A. O. (2015). Water and waterborne diseases: A review. *International Journal of Tropical disease & health*, 1-14.
- Giordano, M. (2009). Global groundwater? Issues and solutions. *Annual review of Environment and Resources*, *34*, 153-178.
- Jagaba, A. H., Kutty, S. R. M., Hayder, G., Baloo, L., Abubakar, S., Ghaleb, A. A. S. & Almahbashi, N. M. Y. (2020). Water quality hazard assessment for hand dug wells in Rafin Zurfi, Bauchi State, Nigeria. *Ain Shams Engineering Journal*, *11*(4), 983-999.
- Kirby, M.; Ahmad, M. (2014). Water Resources Management in Developing Countries: The Role of Hydrology—Economic Modelling; CSIRO: Canberra, Australia.

- Li, P., & Wu, J. (2019). Drinking water quality and public health. *Exposure and Health*, *11*(2), 73-79
- Li, P., He, X., Li, Y., & Xiang, G. (2019). Occurrence and health implication of fluoride in groundwater of loess aquifer in the Chinese loess plateau: a case study of Tongchuan, Northwest China. *Exposure and Health*, *11*(2), 95-107.
- Mgbenu, C. N., & Egbueri, J. C. (2019). The hydrogeochemical signatures, quality indices and health risk assessment of water resources in Umunya district, southeast Nigeria. *Applied water science*, *9*(1), 1-19.
- Mustafa, D., Akhter, M., & Nasrallah, N. (2013). *Understanding Pakistan's water-security nexus*. Washington, DC: United States Institute of Peace.
- Omran, E. S. E. (2012). A proposed model to assess and map irrigation water well suitability using geospatial analysis. *Water*, *4*(3), 545-567.
- Ram, A., Tiwari, S. K., Pandey, H. K., Chaurasia, A. K., Singh, S., & Singh, Y. V. (2021). Groundwater quality assessment using water quality index (WQI) under GIS framework. *Applied Water Science*, *11*, *1*-20.
- Ramakrishnaiah, C.R., Sadashivaiah, C., Ranganna, G. (2009). "Assessment of Water Quality Index for the Groundwater in Tumkur Taluk, Karnataka State, India", *E-Journal of Chemistry*, *6*(2), 523-530.
- Sanjrani MA, Talpur H, Talpur SA (2018) Physiochemical assessment of water sources for drinking purpose in Badin City, Sindh Province, Pakistan, (Water Supply Schemes and Hand Pumps). *Advance Research Journal of Multidisciplinary Discoveries*, *29*(7), 38-44.
- Şener, Ş., Şener, E., & Davraz, A. (2017). Evaluation of water quality using water quality index (WQI) method and GIS in Aksu River (SW-Turkey). *Science of the Total Environment*, *584*, 131-144.
- Shabbir, R., & Ahmed, S.S. (2015). Use of Geographic Information System and Water Quality Index to Assess Groundwater Quality in Rawalpindi and Islamabad. *Arab J. of Sci. Eng.*, *40*, 2033-2047.
- Shen,Y.,Oki,T.,Utsumi,N.,Kanae,S.,Hanasaki,N.,2008. Projection of future world water resources under SRES scenarios: water with drawl. *Hydrol.Sci.J*. 53, 11–33.
- Solangi, G. S., Siyal, A. A., & Siyal, P. (2019). Analysis of Indus Delta groundwater and surface water suitability for domestic and irrigation purposes. *Civil Engineering Journal*, *5*(7), 1599-1608.
- Solangi, G. S., Siyal, A. A., Babar, M. M., & Siyal, P. (2018). Evaluation of surface water quality using the water quality index (WQI) and the synthetic pollution index (SPI): a case study of Indus Delta region of Pakistan. *Desalination and Water Treatment*, *118*, 39-48.
- Solangi, G.S., Siyal, A. A., Babar, M. M., & Siyal, P. (2019a). Evaluation of drinking water quality using the water quality index (WQI), the synthetic pollution index (SPI) and geospatial tools in Thatta district, Pakistan. *Desalination and Water Treatment*, *160*, pp. 202-213.
- Tyagi, S., Sharma, B., Singh, P., & Dobhal, R. (2013). Water quality assessment in terms of water quality index. *american Journal of water resources*, *1*(3), 34-38.
- UNESCO (2002) *Water quality indicator values in selected countries.*
- WHO. 2005. *Guidelines for Laboratory and Field Testing of Mosquito Larvicides, WHO communicable disease control, prevention, and eradication*. WHO pesticide evaluation scheme.
- Wo, N., Hosny, R., Ghareeb, M., Abd-Elhamid, H. F., Zeleňáková, M., & Gad, M. (2025). Assessment of Groundwater Quality and Contamination Hazardous using Water Quality Index and Physicochemical Analysis in Assiut Governorate, Upper Egypt. *Water, Air, & Soil Pollution*, *236*(3), 164.
- Yolcubal, I., Gündüz, Ö. C., & Sönmez, F. (2016). Assessment of impact of environmental pollution on groundwater and surface water qualities in a heavily industrialized district of Kocaeli (Dilovası), Turkey. *Environmental Earth Sciences*, *75*(2), 170.