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Groundwater Quality Assessment of Deltaic Aquifers of Indus Basin: A Case Study of Thatta District, Sindh, Pakistan

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Abstract: This study focuses on groundwater quality for public health in Thatta district that represents a very poor socioeconomic profile. The city has a very limited piped water supply where people mostly rely on well water. For this purpose, groundwater samples were collected from 21 different locations and water quality was assessed for physicochemical and biological analysis using standard methods. Groundwater wells are installed at variable depths (Range: 18 – 70ft). Aesthetically, about 67% samples showed saline taste and three samples are yellow in color or opacity with earthy smell. About half of total samples are turbid (0.03-93 NTU) where four samples (GH-1, GH-3, TH-5, TH-6) showed very high turbidity (5.31-93 NTU). The pH varied in a circum neutral range (6.7-7.4) which is within permissible range (6.5-8.5) of WHO set for drinking water. Conversely, Eh/ORP of all samples remained on lower side (28-120 mv) against WHO guideline range (300-500 mv). Similarly, objectionable hardness (600-2000 mg/L) is reported in all collected samples against WHO limit of 500 mg/L. Likewise, TDS content (567-1609 mg/L) of all and one third samples is above permissible limit of WHO (500 mg/L) and Pakistani guidelines (1000 mg/L) respectively. About half of the samples are reported to be sewage impacted as indicated by the occurrence of pathogenic bacteria. It is concluded that the groundwater is highly polluted due to domestic and agricultural discharge. The problem is further aggravated by poor sanitation conditions and seawater intrusion. None of the water samples met the water quality criteria set by WHO. The groundwater was found to be highly contaminated and possess serious human health risks. Effective measures are urgently required for water quality management in the city.

Keywords: Groundwater, Quality, Drinking, coastal aquifers, Indus delta, Thatta, Sindh.

Introduction

Water is the fundamental need of every individual, and it is their right to have safe drinking water. Life essentially depends on water and its quality. Unfortunately, the recent increase inpopulation results in the shortage of good water quality supply. According to World Health Organization (WHO), about 80% of diseases are water borne. Due to increasing pressure on water supplies, groundwater pollution issues are also growing in many areas of the world. The situation is worsening in underdeveloped countries like Pakistan, where most of the people use contaminated drinking water. In Pakistan, groundwater is one of the critical resources extensively used for drinking, irrigation and industrial purposes. Pakistan is becoming water stressed country and likely to be water-scarce in near future. Pakistan positions at number 80 among 122 countries with respect to drinking water quality. In Pakistan, more than 90% of the total water withdrawal is used for irrigation purposes. It was reported that in the country, about 60–70% of domestic water demands are met through groundwater resources (Ali and Khan, 2021; Sohail et al., 2022; Haider et al., 2023; Khan and Haider, 2024).

About 70% of the rural population in Pakistan have no access to safe drinking water. As a result, patients suffering from water-related diseases occupy about 20–40% of the beds in hospitals, and one-third of all deaths in the country occur due to the use of contaminated water. In the country, every year, about 39,000 children die due to waterborne diseases (Zahid, 2018; Ali and Khan, 2021). Only a few studies have been carried out so far on groundwater quality assessment of coastal areas of Sindh, Pakistan where the groundwater is widely used for drinking and irrigation purposes. In coastal areas up to one billion people utilize groundwater as the major source of drinking throughout the globe. In such areas, seawater intrusion is the main environmental issue for contamination of groundwater. Due to the excessive withdrawal of groundwater, a significant amount of seawater intrudes into the aquifers. The situation is aggravated furthermore by dwindling flows of freshwater from the riverIndus and diminishing precipitation rates due to climate change effects. These studies have reported that groundwater is unfit for human consumption in coastal regions of Pakistan.

This is particularly the case of Thatta district, located in the south of Sindh, where few studies on groundwater quality have been carried out so far. Because of the described scarcity of freshwater, the heavy reliance on groundwater, and the close connection between water quality and human health, it is important to assess the groundwater quality in detail.

Therefore, the present study is aimed at the assessment of groundwater quality in the district Thatta of Sindh province which falls in the deltaic region of the Indus River. This Study comprises physio-chemical and bacteriological analyses supplemented by qualitative approaches, including observations and interviews of people living there. The objectives of this study are to answer the questions on whether the quality of groundwater in the study area is suitable for human consumption, and if not, what are the sources of pollution. Based on these insights, policy recommendations can be made.

Study Area

Thatta is the coastal district of Sindh in south of it (coordinates: 24.7475° N, 67.9106° E), having an area of 17,355km^2 (Fig. 1). It is situated at about 98 km east of Karachi. This district is one of the poorest and least educated(with 36% lowest literacy rate) in the country. Only a quarter of the district's population is considered "economically active" (Memon, 2023). Livelihood of local people is dependent on agriculture due to the nonexistence of industries. Owing to the scarcity of freshwater, the farmers prefer water-resistant crops. The quality of water is one of the major issues in the area that is poor from a public health point of view, but people have no choice except to consume this contaminated water. The present study focuses on two sub-districts of Thatta, namely, Gharo, and Thatta. The groundwater table generally depends on rainwater infiltration that recharges thegroundwater aquifers.

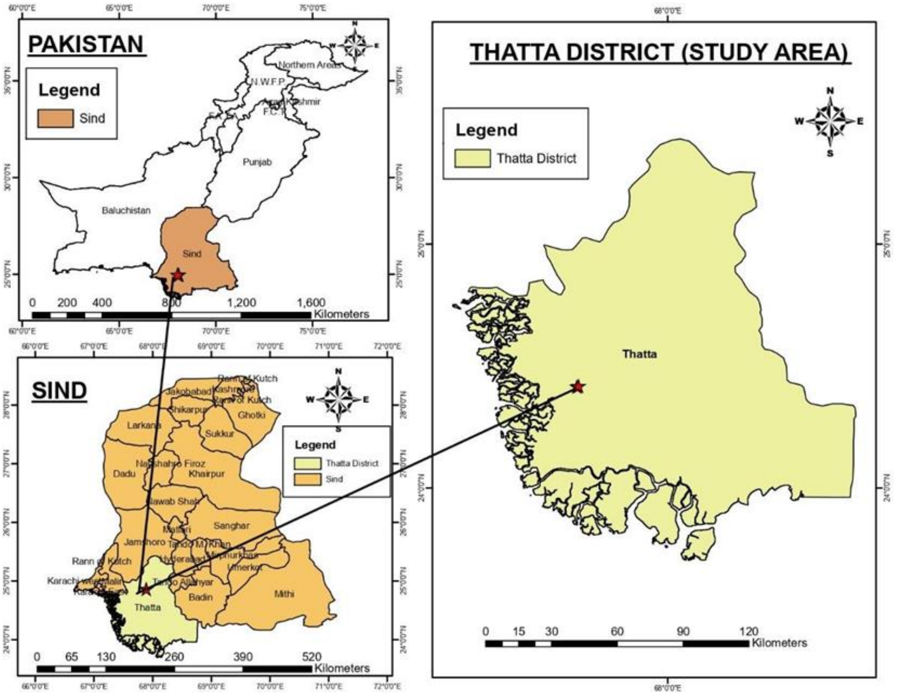

Fig. 1: Administrative map of Thatta District, Sindh, Pakistan.

Hydrogeology of Study Area

Fresh groundwater is available in only 10 % of Sindh's land area, mostly in the form of perched aquifers in friable sandy or silty layers located under clay layers (Haider et al., 2023). The depth of water table varies between 10 and 30 m or even more. About 78 % of the irrigated land in Sindh lies on top of saline or brackish water which cannot be used for agriculture. The few groundwater reserves are overexploited, especially in coastal communities where groundwater is the only water resource available during periods of severe drought and unavailability of canal water. The recharge of groundwater in Thatta district through rain is very low, owing to a low precipitation rate in the area which hardly exceeds 200 mm annually. The predominant source of groundwater recharge is the Indus River where most of the groundwater is drawn from the left bank of the Indus. When the flow of the Indus is low, which commonly happens, the process maybe reversed leading to downstream aquifers being recharged by seawater of the Arabian Sea. This renders water unfit for human consumption.

Material and Methods

Sample Collection

Groundwater samples (n = 21) were collected during the monsoon period before precipitation. These samples were collected from the wells that were dug by hand to the depths of only a few meters. Sampling was carried out by random sampling method from 21 different locations (Fig. 2). Samples were taken from already existing boreholes and hand pump wells. All the water samples were analyzed for differentphysicochemical and biological parameters using standard methods. The obtained results were compared with WHO guidelines available for potable water. Groundwater samples were collected in thousand-milliliters plastic bottles by using standard sample collection methods. The bottles were washed and rinsed properly with distilled water to remove any possible contamination. The aesthetic parameters, such as color, taste and odor were observed in situ. All the collected samples were tagged with a code and sealed with plastic tape. Geographic co-ordinates of the locations, from where the samples were collected, were marked on the sample location map (Table 1). Field proforma was filled in with the required details of the area and samples.

Sample analysis

All samples were analyzed for physicochemical parameters in the laboratory of Department of Geology, University of Karachi. The pH, EC and total dissolved solids (TDS) of the collected samples were measured using specific instruments: a glass electrode pH meter (ADWA AD 111) for pH measurement and an EC meter (ADWA AD 330) for EC and TDS measurement. Sodium and potassium concentrations were determined using a flame photometer (model: PFP-7, JENWAY, UK). Bicarbonate and chloride ions were measured using argentometric titration. The standard EDTA titration method (1992) was employed to determine calcium and total hardness. Magnesium content was estimated by calculating the difference between hardness and calcium using a standard formula. The sulfate content was determined through gravimetric method. Nitrate was measured using the Cadmium Reduction Method (HACH-8171) through a spectrophotometer on groundwater samples preserved in boric acid to stop any reactions that might have reduced the nitrate content. Microbial activity was qualitatively analyzed by using a microbial testing kit with color change from transparent to black grading from negative to very high contamination, respectively.

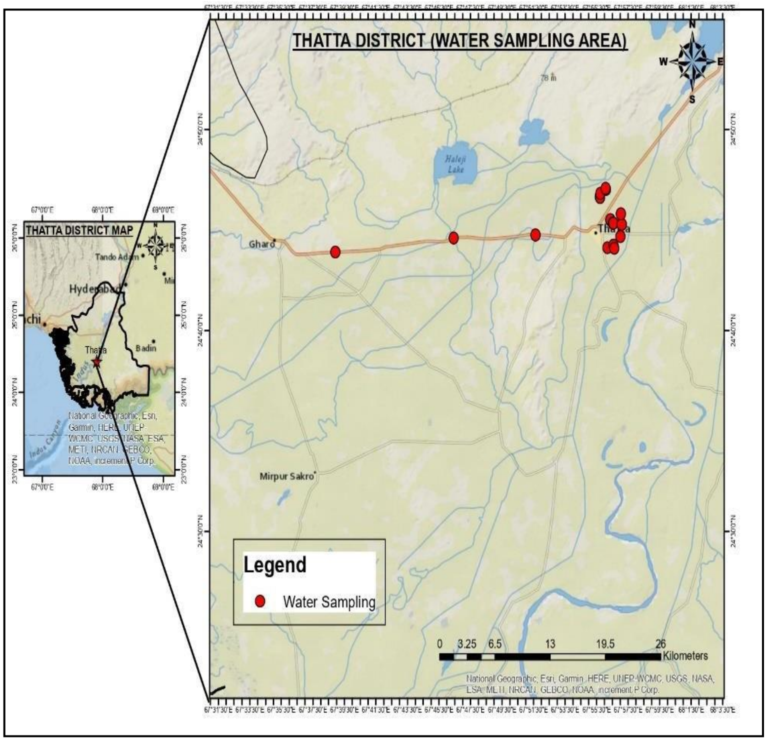

Fig. 2: Map showing the sample locations.

Table 1 Geographic coordinates of sampling sites.

Sample Code	Locality Name	Geographic Coordinates
GH-1	Haji Hotel	24.731456 N, 67.648872 E
GH-2	Gujjo village	24.743082 N, 67.774037 E
GH-3	Dargah Hazrat Muhammad Ali	24.745577 N, 67.860426 E
GH-4	Shaudah Goth	24.735017 N, 67.936705 E
TH-5	Thatta	24.737260 N, 67.942998 E
TH-6	Thatta	24.734540 N, 67.943924 E
TH-7	Thatta	24.744156 N, 67.950219 E
TH-8	Haji Ali Muhammad	24.754517 N, 67.951690 E
TH-9	Haji Ali	24.763204 N, 67.950916 E
TH-10	Allah Dino	24.783427 N, 67.935343 E
TH-11	Allah Dino	24.784182 N, 67.934890 E
TH-12	Muhammad Khan Roonjho	24.780216 N, 67.929106 E
TH-13	Allah Dino Barohi	24.777996 N, 67.929050 E
TH-14	Allah Dino	24.776982 N, 67.928718 E
TH-15	Allah Dino	24.777347 N, 67.928787 E
TH-16	Allah Dino	24.776844 N, 67.928993 E
TH-17	Gulsher	24.758129 N, 67.939595 E
TH-18	Gulsher	24.758366 N, 67.940020 E
TH-19	Yaro Maqsai	24.755628 N, 67.942500 E
TH-20	Yaro Maqsai	24.755472 N, 67.942655 E
TH-21	Yaro Maqsai	24.755434 N, 67.943125 E

Determination of Water Quality Index (WQI)

The Water Quality Index (WQI) is extensively used in many studies related to groundwater quality (e.g. Changsheng et al., 2022; Uddin et al., 2023; Al-Aizari et al., 2024) and has become an efficient means of passing on evidences about quality of water to both concerned policy makers as well as citizens. Weighted arithmetic index method of WQI suggested by (Brown et al., 1970) was used to assess the groundwater quality status of the studied environment. Physicochemical parameters include major cations (Na^+, Ca^{2+}, Mg^{2+}, and K^+), physical parameters like TDS, pH and anions (Cl^-, HCO_3^-, SO_4^{2-} and NO_3^-) were used to calculate WQI of groundwater in studied environment. WQI is calculated by using following expression below:

$$WQI=\sum Q_nW_n / \sum W_n$$

Where, W_n is the unit weight of n^{th} water quality parameter, Q_n is the quality rating of n^{th} water quality parameter.

$$Q_n=100*[(V_n - V_i) / (V_s - V_i)]$$

Where, V_n is the apparent amount of nth parameter present, V_i is the ideal value of the parameter, $V_i = 0$, except for pH ($V_i = 7$), V_s is the WHO standard permissible value for the nth water quality parameter, Unit weight (W_n) is calculated using the formula

$$W_n= k / V_n,$$

Where, k is the constant of proportionality and it is calculated using the equation

$$K= 1 / \sum V_s= 1, 2, \ldots, n$$

Results and Discussion

Physical Parameters

Physical characteristics of collected groundwater samples (n = 21) have been summarized in the (Table 2). Groundwater samples were taken from wells at a depth range of 18 –70 ft (mean depth: 31.5ft). Generally, variation in the water depth is attributed to the affordability, recharging tendency of aquifer or geological variations of aquifer. Since the study area lies in the proximity of Arabian coast, water wells occur at relatively shallow depths due to low relief. Aesthetically, about 67% of samples showed saline taste and three samples are yellow in color or opacity with an earthy smell (Table 2). About half of the total samples are turbid (0.03-93 NTU) whereas four samples (GH-1, GH-3, TH-5, TH-6) showed very high turbidity (5.31-93 NTU). Turbidity is the measure of the relative clarity of the water. It is the function of suspended load including organic particles, bacterio-plankton units, and colloids in water samples (WHO, 2011; Haider et al., 2023). Organic and inorganic matters such as clay, silt, algae, and colored compounds make the water turbid. In the study area, people drain sewage into open pits or channels because they live in semi urban setup where lined sanitation is not yet available. As a result, organic matter and solutes are likely to infiltrate through sediments up to aquifer depths leading to high turbidity. A similar appearance is true for sample no. 7 (at shallow depth) that showed an odor of sewage. As per WHO guidelines, the maximum permissible limit of turbidity in potable water is 5 NTU (Nephelometric Turbidity Unit) but it is ideal if it remains below 1 NTU. High turbidity values in groundwater of study area are prone to causing waterborne diseases such as gastroenteritis, etc. The pH varied in a circum-neutral range (6.7-7.4) which is within the permissible range (6.5-8.5) of WHO set for drinking water. Ideal groundwater expresses neutral pH (pH = 7) where all the cations are in proportion with corresponding anions. However, due to continuous water and rock/sediment interaction, the pH fluctuates in a circumneutral range (6.5–8.5). Excess pH value in potable water may cause nausea, vomiting, damage to certain tissues, or evenkill cause death. Eh (redox potential) is the measurement of the tendency of an environment to oxidize or reduce substrates. Oxidation-reduction potential (ORP) measures the ability of a lake or river to cleanse itself or break down waste products, such as contaminants and dead plants and animals. Eh of all collected samples although positive but remained on a lower side (28-120 mv) against WHO guideline range (300-500 mv). Very high Eh value suggest sufficient availability of oxygen in the water and low bacterial activities (Ali and Khan, 2021; Haider et al., 2022; Haider et al., 2023). This means that bacteria can work more efficiently that decompose dead tissue and contaminants. In general, the higher the ORP value, the healthier the lake, river or aquifer is. Oxygen levels depend on whether water is flowing or steady in nature (Bailey, 2017; Ali and Khan, 2021). In study area, occurrence of relatively low Eh suggest the sewage impact or low recharge of freshwater (Ali and Khan 2021; Haider et al., 2023). Similarly, objectionable hardness (600-2000 mg/L) is reported in all collected samples against WHO limit of 500 mg/L. As per water classification based on hardness (Hem, 1970), if the hardness, is less than 75 mg/L, vary between 75–150, 150– 300 and, is greater than 300 mg/L; the quality of water is categorized as soft, moderately hard, hard, and very hard, respectively. Hence groundwater of the studied environment falls in very hard water category.

Electrical conductivity (EC) varied from 326.3 – 969.17 µS/cm with a mean value of 622 µS/cm. As per WHO guidelines, the allowable limit of EC for potable water is 400 µS/cm where about only 10% of total samples qualify to fit in the desirable limits. Likewise, total dissolved solids (TDS) content (range: 567-1609; mean:1042.2 mg/L) of all and one-third samples is above permissible limit of WHO (500 mg/L) and Pakistani guidelines (1000 mg/L) respectively. TDS content is one of the primary parameters used for the assessment of water quality. High level of TDS content in drinking water is evidence of ionic imbalance which leads to the severe health impacts (Khan et al. 2017). TDS content increases with the increased water-soil/rock interaction (WHO, 2011). The extremely high values of TDS content were observed in sample TH-1 and TH-20. It is observed that high TDS is found in both shallow and relatively deeper wells, but generally, wells with more depths have relatively low TDS content. This clearly indicates that high input of sewage mixing and other salts infiltrating from the surface due to urban setup are making shallow aquifers more saline. In general, seawater intrusion, lack of aquifer recharge and increased concentration of dissolved solids are the responsible factors for a higher level of TDS in the groundwater of study area. About half of the samples are reported to be sewage impacted as indicated by the occurrence of pathogenic bacteria. The occurrence of pathogenic bacteria in drinking water of study area suggests the water may contain pathogens that can cause diarrhea, vomiting, cramps, nausea, headaches, fever, fatigue, and even death sometimes (WHO, 2011).

Fig. 3: Sewage water occurring in Thatta leading to bacterial contamination in shallow aquifers.

Table 2: Physical Properties of Collected Groundwater Samples

Sample No	Well depth (ft)	Color	Taste	Smell	Hardness (mg/l)	Turbidity NTU	pH	Eh (mv)	TDS (mg/l)	EC (mS/cm)	Bacterial Test
1	60	Yellow	Saline	-	1400	5.31	7.37	105	1524	541	Positive
2	18 – 20	Colorless	Non-Saline	-	800	0	7.18	81	693	450.45	Positive
3	35 – 50	Opaque	Non-Saline	Earthy	600	93 (high)	7.21	113	1260	819	Positive
4	40 – 45	Colorless	Non-Saline	-	1000	0	7.02	100	900	585	Negative
5	70	Colorless	Non-Saline	-	1000	8.38	7.38	114	884	574.6	Positive
6	40 – 50	Yellowish	Saline	-	2000	36.91 (high)	6.72	28	718	467	Negative
7	18 – 20	Colorless	Saline	Sewage	600	3.16	7.31	120	1502	326.3	Positive
8	20	Colorless	Saline	-	800	1.16	7.07	100	932	605.8	Positive
9	30	Colorless	Saline	-	800	0	7.07	117	989	642.85	Positive
10	20- 25	Colorless	Saline	-	800	0	7.39	116	694	451.1	Positive
11	20 – 21	Colorless	Saline	-	1200	0	7.29	112	804	522.6	Negative
12	35	Colorless	Non-Saline	-	1000	0	7.25	117	981	638	Negative
13	20 – 21	Colorless	Non-Saline	-	600	0	7.29	118	567	368.55	Positive
14	21	Colorless	Saline	-	1000	0	7.4	104	1133	865	Negative
15	20 – 25	Colorless	Saline	-	600	0.99	7.39	105	1301	872	Negative

Continuing Table 2: Physical Properties of Collected Groundwater Samples

Sample No	Well depth (ft)	Color	Taste	Smell	Hardness (mg/l)	Turbidity NTU	pH	Eh (mv)	TDS (mg/l)	EC (mS/cm)	Bacterial Test
16	20 – 25	Colorless	Saline	-	1200	0	7.11	108	1401	917	Negative
17	70	Colorless	Saline	-	1000	0	7.05	79	1469	644.07	Negative
18	70	Colorless	Saline	-	600	0	7.37	80	891	579.15	Positive
19	25	Colorless	Non-Saline	-	800	2.51	7.07	90	846	549.9	Negative
20	20-30	Colorless	Saline	-	1400	0	7.0	70	1609	969.17	Positive
21	35	Colorless	Saline	-	800	0.03	7.14	84	998	676.41	Positive
WHO LIMITS		Colorless	Non-Saline		500	5	6.5 – 8.5	300-500	500	400	Negative

Chemical Properties

Chemical properties of water samples have been summarized in Table 3. Chemical properties of water are a function of dissolved salts and minerals found in rocks or soil.

Table 3: Chemical properties of groundwater from Thatta district.

Major Cations					Major Anions			
Sample No.	Na	K	Ca	Mg	Cl	NO_3^-	SO_4^{-2}	HCO_3^-
1	1525	60	24	325.62	3191.4	0.41	854.7	798
2	390	15	136	111.78	212.76	0.35	293.04	315
3	690	39	24	131.22	496.44	0.04	284.9	462
4	472	17	80	194.4	283.68	0.39	203.5	378
5	530	32	48	213.84	354.6	0.27	138.38	357
6	1670	30	240	340.2	5035.32	0.71	504.68	357
7	340	20	88	92.34	212.76	0.01	179.08	231
8	460	22	112	126.36	141.84	0.44	333.74	315
9	500	24	104	131.22	425.52	0.32	211.64	399
10	390	40	136	111.78	141.84	0.77	227.92	336
11	432	40	32	272.16	283.68	0.01	350.02	336
12	446	32	88	189.54	425.52	0.11	252.34	273
13	324	23	48	116.64	142.84	0.12	163.64	294
14	712	48	48	213.84	1241.1	0.44	236.06	357
15	720	26	40	121.5	996.44	1.04	309.32	420
16	614	34	104	228.42	996.44	0.27	26.140	420
17	884	40	96	184.68	1170.18	0.26	380.020	441
18	578	28	48	116.64	354.6	0.11	364.660	420
19	456	22	40	170.1	283.68	0.72	521.580	273
20	600	40	152	247.86	780.12	1	432.540	315
21	520	40	576	155.52	390.06	0.5	414.000	357
WHO LIMIT	200	12	100	75	250	50	250	500
All values are in milligram per liter (mg/L)								

Major Cations

Highly variable concentration of sodium (range:324-1670; mean: 598.58mg/L) and potassium (range:15-60; mean: 32 mg/L) is observed in groundwater of study area. Both these ions are above WHO prescribed corresponding permissible limits of 200 and 12 mg/L respectively. Mean concentrations of sodium and potassium are almost three times higher than the permissible limits. The high concentration of sodium ion is due to the proximity of

Arabian sea in study area. Similar, increasing potassium in groundwater seems to be the result of intensive agricultural activities, seawater intrusion and sewerage mixing (Ali and Khan, 2021; Haider et al., 2023). Moreover, it might have come from the weathering of feldspar and clay minerals from the aquifer matrix as feldspar are susceptible to weathering and alterations (Khan et al., 2020). On the other hand, calcium and magnesium contents ranged between 24 – 576 mg/L and 92.34 - 325.62 mg/L, respectively. While the desirable limit for Ca^{2+} and Mg^{2+} is 100 mg/l and 75 mg/L, respectively. About half of the samples exceeded corresponding limits of Ca^{2+} and Mg^{2+} set for drinking water by WHO (Table 3).

Table 4: Statistical descriptive of physicochemical parameters of groundwater samples

S. No.	Parameter	Minimum	Maximum	Mean	Standard deviation
1	Well depth(ft)	20	70	41.77	21.81
2	pH	6.72	7.4	7.19	0.187
3	Eh(mv)	28	120	97.76	23.97
4	TDS (mg/L)	567	1609	1042.294	309.71
5	EC (ms/cm)	326.3	969.17	627.17	186.58
6	Turbidity (NTU)	0	8.38	1.014	2.196
7	Bacterial activity	0(negative)	1(positive)	0.529	0.514
8	Hardness(mg/L)	600	2000	952.94	357.23
9	Na^+(mg/L)	324	1670	598.58	8.383
10	K^+(mg/L)	15	60	31.82	8.38
11	Ca^{2+}(mg/L)	24	576	117.65	129.42
12	Mg^{2+}(mg/L)	92.34	325.62	178.39	67.64
13	Cl^-(mg/L)	141.84	5035.32	786.85	1155.58
14	NO_3^-(mg/L)	0.01	1.04	0.418	0.328
15	SO_4^{2-}(mg/L)	26.14	854.7	296.81	134.48
16	HCO_3^-(mg/L)	231	798	347.12	59.91

Major Anions

Concentration of major anions varied in the order of $Cl^- > HCO_3^- > SO_4^{2-} > NO_3^-$ Extremely wide concentration variation for Cl^- (range: 141-5035; mean:787 mg/L), HCO_3 (range: 231-798; mean: 347 mg/L), SO_4 (range: 26-854; mean:297 mg/L) and NO_3 (range: 0.01-1.04; mean: 0.418mg/L) contents occurs in the groundwater of study area. It is well established that chloride dominate in fresh or recently recharged groundwater (Khan and Bakhtiari, 2017; Khan et al., 2020). About 81% samples for each Cl and HCO_3 and 28.6% for sulphate content are above corresponding permissible limits set by WHO for drinking purpose. The dominance of chloride ion in the groundwater of Thatta district clearly indicates the anthropogenic input and seawater intrusion (Ali and Khan, 2021; Haider et al., 2023). Similarly, occurrence of elevated bicarbonate content (> 700 mg/L) against WHO permissible limit (300 mg/L) suggests active biodegradation of organic matter (Ali and Khan, 2021; Haider et al., 2023). Since the study area is part of Indus delta and surrounded by agricultural belt, organic matter decomposition is ubiquitous process leading to high bicarbonate content in groundwater of study area (Ali and Khan, 2021; Haider et al., 2023). On the other hand, nitrate concentration is within permissible limit (Table 3). The low level of NO_3^- is either attributed to the occurrence of less oxic water or low organic matter for the bacterial degradation (WHO, 2011). Since the area lies in the deltaic agricultural region, the occurrence of high organic matter is obvious as indicated by very high bicarbonate content in the groundwater of the study area (Naseem et al., 2018). Hence, the prevalence of less oxic water seems to be the factor responsible for the occurrence of low nitrate content in the groundwater of the study area.

Water Quality Index of Study Area

The (WQI) method known as weighted arithmetic index is applied to measure the quality of shallow and deep wells in the present environment. This method explicitly promises to deliver a solitary value that signifies the overall water quality by seeing several variables and their concentrations in collected samples. The resulting value suggests a complete understanding of water quality and its suitability for different purposes such as irrigation, industrial as well as for potable use (Abbasi and Abbasi, 2012; Changsheng et al., 2022; Uddin et al., 2023; Al-Aizari et al., 2024). To calculate the WQI for groundwater, the first step requires approximating the quality rating (Q_n) for each parameter using the formula: $Q_n = 100 * [(V_n - V_i) / (V_s - V_i)]$. A quality rating of $Q_n = 0$ describes the absence of pollutants, while $0 < Q_n < 100$ directs about the pollutants that are within the prescribed standards. A Q_n value greater than 100 indicates that the pollutants exceed the standards (Gungoa, 2016; Changsheng et al., 2022; Uddin et al., 2023; Al-Aizari et al., 2024). In these collected samples, the quality ratings (Q_n) for variables such as TDS, K^+, Na^+, Ca^{2+}, HCO_3^-, Mg^{2+}, NO_3^-, Cl^-, hardness and SO_4^{2-} are all above 100, as mentioned in Table 5. This indicates that these components are the main factors contributing to the deterioration of water quality.

Table 5: Water quality index of collected groundwater samples.

	pH	TDS	Hardness	Na	K	Ca	Mg	Cl	NO3	HCO3	SO4
Parameters	-	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Observed Value (V_n)	7.19	1042	952.94	599	32	118	178	787	0.417	347	280
WHO Limits (V_s)	8.5	500	500	200	12	75	150	250	10	300	250
Ideal Value (V_i)	7	0	0	0	0	0	0	0	0	0	0
Q_n	-9.04	753.6	380	491	234	504	154.7	848.8	450	131	229
$W_n=k/V_n$	0.407	0.00281	0.00307	0.00489	0.09208	0.02490	0.0164	0.00372	7.0263	0.0084	0.0104
Q_n*W_n	5.1617	0.586	0.586	1.465	24.41667	3.9066	1.9533	1.172	29.3	0.9766	1.172
$\sum W_n = 7.600, \sum Q_nW_n = 70.69,$										**WQI = 9.30**	

The second stage is to compute the unit weight (W_n) for all the physico-chemical variables using the expression: $W_n = k / V_n$, as shown in Table 5. The calculated WQI results (Table 5) indicate that the groundwater in studied environment is unfit for drinking purpose, as suggested by (Brown et al., 1972). The water quality of the collected samples was deemed fit for drinking, with a WQI value of (WQI = 9.30). This indicates that suitable groundwater treatment is essential prior for any usage or intake by individuals.

Table 6: WQI range, status and possible usage of groundwater (Brown et al., 1972).

WQI	***Status***	***Possible usages***
0–25	Excellent	Drinking, irrigation and industrial
25–50	Good	Domestic, irrigation and industrial
51–75	Fair	Irrigation and industrial
76–100	Poor	Irrigation
101–150	Very poor	Restricted use for irrigation
Above 150	Unfit for drinking	Proper treatment required before use

Conclusion

Present study revealed that the groundwater of Thatta district is marginally fit for drinking in terms of its physicochemical and microbiological character. Major chemistry of groundwater is badly hampered by sewage contamination due to poor sanitation conditions and agricultural discharge. The problem is further aggravated by seawater intrusion. Due to excessive discharge rates of groundwater, a significant amount of seawater has intruded into the aquifers. The situation is further aggravated by dwindling flows of freshwater from the river Indus. No proper system for the discharge of sewerage water. Shallow aquifers and improper filtration of used water. Hence, it is concluded that none of the water samples met the water quality criteria set by WHO and possess serious human health risks. Moreover, depth of the wells in study area is generally very shallow, which led to the contamination of groundwater through unlined sanitation (toilets and surface runoff). Thus, both geogenic and anthropogenic factors have contributed to the contamination of groundwater in the study area. Effective measures are urgently required for water quality management in the city.

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