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Ground Water Quality Assessment of Orangi Town, Karachi, Pakistan: The Largest Slum Area of South Asia

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Abstract: This study focuses on assessing the hydrogeochemical characteristics of groundwater of Orangi Town situated in the western district of Karachi and determining its quality through the Water Quality Index (WQI) method. To achieve this objective, a total of 20 groundwater samples were collected from different sites in Orangi Town. Sampling depth varied from 12 to 350 ft, and the age of wells spanned between 1-15 years. The groundwater quality revealed significant variations in various physicochemical parameters, presenting ranges as temperature (25.1-26.5 °C), pH (5.67-7.29), EC (1953.12-23125 µS/cm), TDS (1250-14800 ppm), turbidity (0.00-5.00 NTU), hardness (800-7800 mg/L), Mg^{2+} (6.1-1530 mg/L), Ca^{2+} (88-933 mg/L), K^{+} (11-46 mg/L), Na^{+} (300-3398 mg/L), SO_4^{2-} (78-3293 mg/L), HCO_3^{-} (200-580 mg/L), NO_3^{-} (1.21-31.98 mg/L), Cl^{-} (70-10779 mg/L). The results, compared with World Health Organization (WHO) and U.S. Environmental Protection Agency (EPA) standards, revealed that except pH, all physicochemical parameters are exceeding the corresponding limits for drinking purposes. The calculated Water Quality Index (WQI) value (206.83) provides clear evidence that the groundwater in Orangi Town is unfit for drinking purpose. The Piper diagram illustrates that the dominant hydrochemical facies include chloride-type water, mixed calcium-magnesium-chloride, and sodium chloride types indicating that diverse sources are influencing groundwater chemistry.

Keywords: Groundwater, Drinking Quality, WQI, Orangi Town, Karachi, Pakistan.

Introduction

Clean water is imperative for human's life especially for drinking water. Millions of people in developing countries like Pakistan still have no access to safe and adequate water supply. The population without access to safe water in urban areas is increasing sharply in developing countries due to rapid industrialization and urbanization, much of which occur in peri-urban and slum areas since the last decade. The United Nations has projected a rapid population growth in urban areas between 2000 and 2030, suggesting that 6 out of 10 people will be living in cities. Therefore, accessible and adequate safe drinking water and sanitation in urban areas particularly for urban poor dwellers should be prioritized by policy advancement and implementation.

Groundwater serves as a fundamental source of potable water (Ahmed *et al*., 2006). It accounts for more than 90% of the planet's freshwater resources and represents a significant reservoir of high-quality water (Kanmani & Gandhimathi, 2013). Globally, 97% of freshwater resources are found in groundwater, which is also major source of freshwater for domestic industrial, and irrigation purposes (Ravenscroft & Lytton, 2022; Li *et al*., 2023). Groundwater plays a key role in fostering development, especially in arid and semi-arid regions with limited precipitation and surface water (Tian *et al*., 2017; Chen *et al*., 2017). The quality of groundwater has emerged as a critical concern due to rising population growth, rapid industrialization, unplanned urban expansion, and extensive use of fertilizers and

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pesticides in agriculture (Joarder *et al*., 2008). Its quality is influenced not only by natural factors such as the characteristics of recharging waters, groundwater flow rates, aquifer geology, and interactions with other aquifer types but also by human activities like industrial processes, agricultural practices, pollution discharge, and groundwater extraction, which alter the hydrological cycle (Helena *et al*., 2000; Jiang *et al*., 2009). Groundwater is a precious resource for drinking water, domestic usage, industrial applications, and agriculture. Generally, it exhibits favorable quality compared to other water sources, primarily due to natural filtration processes in the soil (Annapoorna & Janardhana, 2015; Orang & Khalid, 2019).

Nevertheless, variations in groundwater quality depend upon the geological formations, it traverses and human activities in proximity to the groundwater basin (Kawo & Karuppannan, 2018). Although, quality of groundwater is essential for human health food security, agriculture, ecosystem preservation, and the economic growth of societies (Ahmed *et al*., 2020; Elzain *et al*., 2024a). However, it is compromised over quantity needed for the survival.

According to the UN- Habitat, about thirty-three percentage of urban developing population were living in slums. In India, Bombay, where highest number of people is living in slums, nearly half of the populations in Bombay were living in small shacks, which are surrounded by open drains. Similarly, after the partition of India-Pakistan, a large population migrated to Karachi city, the biggest city of Pakistan out of which a large section of people was settled in camps of suburbs and outskirts where Orangi town is known as one of the largest slum areas of Asian continent. Unfortunately, very limited water supply has been provided to the dwellers of this town for a long duration. Due to the scarce supply of water with an exponentially growing population, people turned towards groundwater as an alternative source of life. Despite the largest settlement with dense population, no groundwater quality data is available on the potability of groundwater for the residents. Hence, present study aims to assess groundwater quality using hydrogeochemical characteristics of Orangi Town, Karachi. Another objective is to verify water quality through the water quality index determination method for providing an objective assessment of the quality for intended uses.

Materials and methods

Study Area

Orangi Town (OT) is situated in the western district of Karachi, Sindh. It was established in 2001 as a result of the local government ordinance and was initially divided into 13 union councils. The administrative structure changed in 2011, and 2015, Orangi Town was re-mapped and incorporated into the Karachi west district. The surface geology of Karachi is dominated by Tertiary and Quaternary age rocks comprising Eocene to Pliocene rocks. This sedimentary package includes the Manchar Formation of Pliocene, Gaj Formation of Miocene, and Nari Formation of Oligocene age, which are exposed at various sites in the city and dominated by the occurrence of limestone, sandstone, shale, and clay (Akhtar & Dhanani, 2012; Qureshi *et al*., 2001).

Structurally, the study area rests on the periphery of the Pir Mango anticline in the southwest Figure 1. The anticline is tightly folded, resulting in steeply dipping strata (> 30° dip). Lithologically, OT lies in the Mol and Mundro members of the Gaj Formation and the Orangi sandstone member of the Nari Formation Figure 1. Orangi stream passes through the middle of the town and serves as a sewerage line for draining wastewater. This Orangi Nala is a potential threat to the good water resources of OT in terms of microbiological contamination followed by chemical pollution.

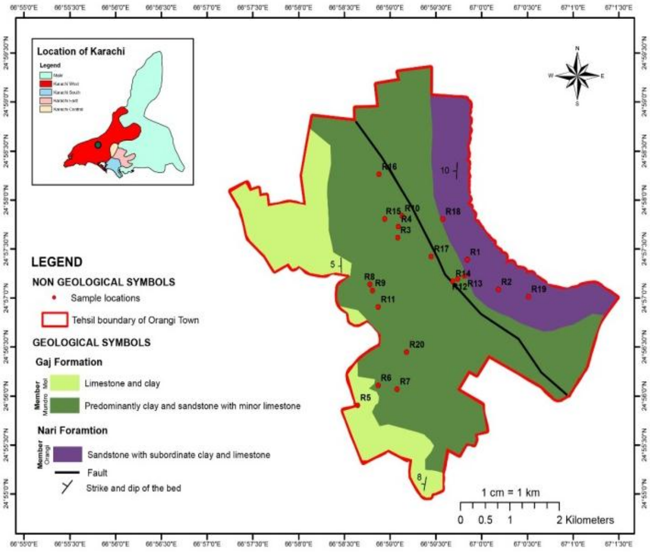

Figure 1: Geological map of Orangi Town section digitized from the geological map of Karachi area, Sindh, originally published by the Geological Survey of Pakistan (Qureshi & Ahmad 2001).

Sampling

A total of 20 groundwater samples were collected randomly from electrically pumping wells (EPW) located at different sites within OT, as indicated in Figure 1. Out of the total (n = 20), seven each were collected from eastern (R2, 4, 10, 15, 16, 18, 19) and western bank (R5, 6, 7, 8, 9, 11, 20) of Orangi Nala while six samples were collected from (R1, 3, 12, 13, 14, 17) nearby stream Figure 2. The samples were collected in one-liter plastic bottles from various depths (12 to 350 ft) whereas the age of wells ranged between 1-15 years Table 1. Boring wells were run for two minutes before sampling to get representative samples after removing the standing water. Sampling bottles were cleaned thoroughly with distilled water and rinsed with the sample water before collection. For nitrate determination, 100 ml bottles were used separately. Boric acid solution (1%) was poured into a 100 ml bottle to cease any reaction, reducing the nitrate content.

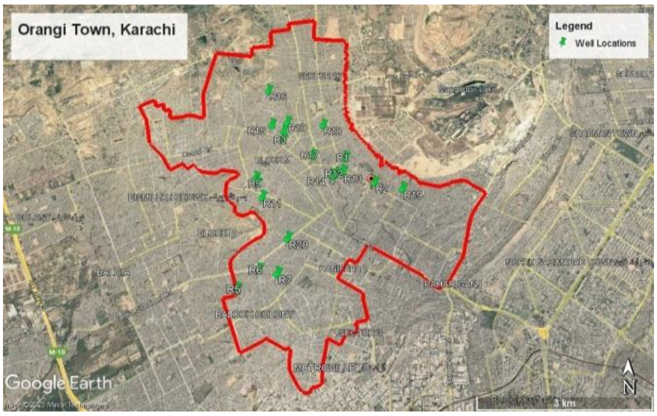

Figure 2: Map displaying the sampling locations within Orangi Town, Karachi.

Groundwater Analysis

The analysis of groundwater samples was conducted in the laboratory of the Department of Geology at the University of Karachi. This analysis aimed to determine various physicochemical parameters through a careful standardization process and precise measurement procedures. The odor and taste were determined aesthetically, while the color of groundwater was assessed through visual observation. The measurement of turbidity in groundwater samples was conducted with the use of a turbidity meter (HANNA instruments, model HI 937073-11), while pH and temperature were determined using an ADWA (AD 111) pH meter. Total dissolved solids (TDS) and electrical conductivity (EC) of the samples were measured employing a TDS meter (Eutech cyberscan). Nitrate levels were determined using a Genesys 10s UV-VIS Spectrophotometer by Greenberg method (Greenberg *et al.*, 1992). Bicarbonate and calcium in groundwater samples were quantified using the standard EDTA titration method. For bicarbonate, 0.02N HCL along with methyl orange indicator was used until the color of sample changed from pink to dark orange whilst 0.01N and 0.1N EDTA solution was used with Murexide (Ammonium purpurate) as indicator was used until the color of solution changes from pink to dark blue. Hardness was determined using the calcium carbonate EDTA titration method (Greenberg *et al.*, 1992). The concentration of 0.1N and 0.01N EDTA was also used along with 1-2ml buffer solution as well as with EBT indicator so that the original solution color changes from pink to sky blue. The magnesium content was calculated as the variance between hardness and calcium levels, employing a standard formula as shown in Table 1. Na+ and K+ concentrations were measured using a Flame Photometer (Model: PFP-7, JENWAY, UK), whereas sulfate concentration was assessed through the gravimetric method. This sulfate method follows the procedure outlined in (Greenberg *et al.*, 1992) where 50ml of the original solution was taken in a beaker, added 3 drops of HCL, and the mixture was heated gently for 15 minutes, then, anhydrous barium chloride was added to precipitate $BaSO_4$, which was filtered through Whatman filter paper no 42. After that, empty crucibles were weighed on a digital balance of 0.0001g accuracy, the filter paper containing the precipitate was placed into the crucibles and then heated at around 900°C in a muffle furnace for 3 hours. After heating, the crucibles were cooled in a desiccator and the final weight, including the sulfate content, was recorded. The sulfate value was calculated by subtracting the initial weight from the final weight and multiplying the difference by a constant.

Table 1: Groundwater variables analyzed according to the below methods.

Parameters	**Instruments/Methods**
Odour and taste	Aesthetically
pH	ADWA (AD111) pH meter
Colour	Visual observation
Turbidity	Hanna Portable HI-93102 meter
TDS/EC	ADWA(AD330) TDS/EC/T°C meter
Hardness	EDTA titration method
Chloride	Argentometric titration method (Greenberg *et al.*, 1992)
Bicarbonate	Titration method (Greenberg *et al.*, 1992)
Nitrate	Genesys10s Uv-Vis spectrophotometer
Sulfate	Gravimetric method (Greenberg *et al.*, 1992)
Sodium	JENWAY PFP7 Flame Photometer
Potassium	JENWAY PFP7 Flame Photometer
Calcium	EDTA titration method (Greenberg *et al.*, 1992)
Magnesium	Standard formula; Mg = [(Hardness-(Calcium.2.5)] x0.243

Statistical Analysis

For the experimental dataset, calculations were performed using an Excel spreadsheet to determine the minimum, maximum, average, correlation matrix, and Water Quality Index (WQI) for each combination of water quality parameters. The WQI was determined through the weighted arithmetic index method (Brown *et al.*, 1970). In this calculation, the following parameters were included: pH, TDS, EC, hardness, Na^+, K^+, Ca^{2+}, Mg^{2+}, HCO_3^-, Cl-, SO_4^{2-}, and NO_3^-. Further, chemical parameters of groundwater were plotted on Piper diagram vision to determine hydrochemical facies. Moreover, spatial map was created by using the software Arc GIS and Surfer 11.

Results and discussion

Physical Attributes

The data summarizing the physical and chemical attributes of the collected groundwater samples (n = 20) are presented in Tables 2 and 3, respectively. The results have been compared with World Health Organization (WHO) and the U.S. Environmental Protection Agency (EPA) standards for corresponding permissible limits (WHO, 2011; US EPA, 2023). A slight variation of 25.1-26 °C in the temperature has been observed, suggesting the same aquifer system and less susceptibility to alterations. The pH of groundwater is generally acidic (mean: 6.79) which varies between 5.67-7.29. The pH of a water system plays a direct role in all chemical and biological reactions (Rao *et al*., 2006). TDS content fluctuates between 1250- 14800 mg/L with a mean of 8779.6 mg/L. This level is more than eight times higher than the WHO and EPA drinking water standard of 500 mg/L. According to the classifications of TDS (Todd & Mays, 2005), the groundwater of Orangi Town is brackish to saline Fig. 3 on the other hand, groundwater hardness ranges between 800-7800 mg/L which also violates the WHO permissible limits (500 mg/L). The hardness of water primarily relies on the concentration of calcium and magnesium salts (Singh *et al*., 2012). It is consistent with the fact that Ca^{2+} and Mg^{2+} contents are above permissible limits Table 6. Turbidity levels in all the samples collected were measured at 0.5 NTU, indicating the presence of finely divided solids that cannot be easily removed through standard filtration methods. The presence of turbidity in water can impact its acceptability to consumers. Moreover, there is a concern that turbidity particles may provide a shield for pathogenic organisms, potentially allowing them to evade the effects of disinfection (Istifanus Chindo *et al*., 2013).

Chemical Attributes

The summary of the chemical attributes of groundwater samples is provided in Table 5. The average concentration of Mg^{2+} in the groundwater of Orangi Town was found to be 414.80 mg/L, exceeding the corresponding limit except for one sample (R19) 6.1 mg/L respectively. Mg^{2+} is abundant in nature and contributes significantly to water hardness, often imparting an unpleasant taste to water (Konso, 2017). On the other hand, calcium levels in groundwater ranged from 88 to 933 mg/L, with an average value of 475.05 mg/L, surpassing the WHO (2011) limit for drinking purposes. Furthermore, the potassium content in the groundwater varied between 11 and 46 mg/L, with an average of 25.7 mg/L, which is twice the recommended WHO limit of 12 mg/L for drinking water. Potential origins of potassium in groundwater encompass precipitation, the weathering of existing potash silicate minerals, and excessive application of potash fertilizer (Jain & Sharma, 2011; Deshpande & Aher, 2012). Sodium concentrations ranged from 300 to 3398 mg/L, exceeding the permissible limit of 200 mg/L. Elevated sodium levels could stem from the dissolution of subsurface strata or anthropogenic activities (Dieng *et al*., 2016). High sodium content in the groundwater of OT is attributed to the sandy layers of Orangi members exposed which is followed by sewage water infiltration. Extremely high content of SO4 was determined in all collected samples except in one sample (R3) which contains a minimum concentration of 78 mg/L while the maximum concentration is about 3293 mg/L with an average value of 1238.33 mg/L. This high sulfate in the groundwater of OT is also associated with the dissolution of gypsum from shale units and the sewage water mixing within the groundwater. Bicarbonate content varied in the range of 200 – 580 mg/L with a mean value of 404 mg/L. Only a couple of samples (R6 and R16) exceeded the WHO's allowable threshold of 500 mg/L. The slightly elevated bicarbonate content in these two samples can be attributed to natural sources. Bicarbonate is primarily derived from the CO_2 present in the soil zone during the weathering of the parent rock (Kenneth *et al*., 2014). Potential origins of bicarbonate may involve the dissolution of silicate minerals and the interaction between feldspar and carbonic acid when in the presence of water (Hem, 1991). The nitrate content ranged from 1.21 to 31.98 mg/L, with an average of 14.25 mg/L. Approximately half of the total samples exceeded the WHO's allowable limit of 10 mg/L Table 6. The elevated content of NO^{3-} in the groundwater of OT is attributed to the fact that it is a highly soluble and mobile radical. Relatively high nitrate content is also due to the mixing of sewage water from Orangi Nala. Moreover, it is also suggesting the fresh infiltration of surface water. When there is a high concentration of nitrate in drinking water, it becomes toxic (Umavathi *et al*., 2007). Chloride concentration fluctuated within the range of 70 – 10779 mg/L where all the samples had elevated chloride content except sample (R3). The predominant source of chloride concentration in groundwater can be attributed to atmospheric sources or seawater contamination. These concentrations may increase due to various factors such as base-exchange phenomena, high temperatures, domestic effluents, septic tanks, and low rainfall. Additionally, the porosity of the soil and its permeability plays a significant role in the accumulation of chloride (Istifanus Chindo *et al*., 2013). Consequently, the chemical composition and formation of groundwater are regulated by the geological environment, which is a product of lengthy geological evolution processes (Wu *et al*., 2015).

Ionic inter-relationships

The connections between TDS and the major ions are valuable for understanding the principal hydrogeochemical evolution processes that occur within an aquifer. These relationships can also be employed to gather the origins of ions and the source of groundwater (Kumar *et al*., 2009). The correlation between different parameters of groundwater samples has been condensed in Table 7. They highlight significant relationships among parameters. Notably, TDS display strong positive correlations with cations (Na^+, Mg^{2+}, Ca^{2+}) and anions (Cl^-, SO_4^{2-}) suggesting these ions share a common geological origin. The correlation of EC and TDS with multiple cations underscores geological mineralization effects. Na^+ and Cl^- exhibit a substantial positive correlation, implying a shared source, potentially linked to saline geological formations. Moreover, Hardness shows positive correlations with Ca^{2+}, Mg^{2+}, and Na^+ highlighting the influence of geology on water mineral content. While pH negatively correlated with many elements, suggests additional influences beyond direct geology. These correlations collectively emphasize the intricate interplay between geological processes, water chemistry, and hydrogeological characteristics shaping the composition of the groundwater.

Water Quality Index

Water Quality Index (WQI) is a numerical measure used to assess water quality by considering various parameters. Lower values indicate good or excellent quality, while higher values indicate poor or bad quality, as explained by Bharti & Katyal (2011). WQI was initially formulated by (Horton, 1965) and has gained widespread usage and acceptance in numerous European, African, and Asian countries (Horton, 1965). It was further generalized by (Brown *et al*., 1970), which was based on weights to individual parameters. The water quality status of the groundwater in Orangi Town was assessed using the weighted arithmetic index method for WQI developed by (Brown *et al*., 1970). A combination of physical and chemical parameters, encompassing TDS, pH, depth, temperature, hardness, and major cations and anions, was utilized to calculate the water quality index for the study area. Types of water According to WQI, results of groundwater span between 200 – 300 suggesting that is very poor water quality (Sahu & Sikdar, 2008). The results of WQI of Orangi Town are about 206.83 which indicates that the groundwater is classified as very poor water Table 9.

Hydrochemical Facies

The Piper trilinear diagram was created by using physicochemical data from groundwater in the study area Figure 5. It is a graphical method that is used to analyze the hydrochemical characteristics of groundwater (Karakuş, 2019). Hydrochemical facies help to determine the source and classification of various types of water (Kada & Demdoum, 2020). Plotting that sample data on the Piper diagram reveals that groundwater is dominant in chloride type in the study area due to its higher occurrence, followed by a mixed type (Ca-Mg-Cl). Additionally, some samples are categorized as sodium chloride type (Na-Cl). This suggests that the primary hydrochemical facies in the groundwater originate from chloride-rich sources, possibly influenced by geological factors or anthropogenic activities.

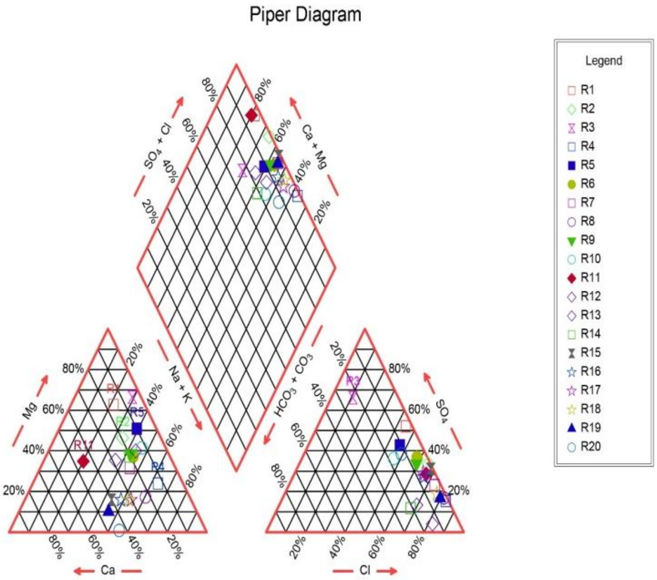

Figure 5: Piper Diagram representing groundwater samples from the study area.

Conclusion

Groundwater quality in Orangi Town, Karachi, as assessed through various physicochemical parameters and water quality index (WQI), is found to be highly unsuitable for drinking purposes. Most major cations, anions, and physical parameters of the groundwater exceed the (WHO, 2011) and (EPA, 2023) standards for safe drinking water. The WQI value of 206.83 categorizes the groundwater as very poor, indicating significant contamination and deterioration. This water should be treated properly before being used for drinking and other domestic purposes. Further studies should be carried out to screen western parts of the study area with a special focus on microbiological screening.

Table 2: Aesthetic properties of groundwater samples.

Sample code	Depth (ft)	Age of well	Color	Odor	Taste
R1	125	4 years	Clear	UO	Saline
R2	170	3 years	Clear	UO	Saline
R3	110	5 years	Clear	UO	UO
R4	100	6 years	Clear	UO	Saline
R5	150	2 years	Clear	UO	Bitter
R6	450	3 years	Clear	UO	Saline
R7	290	7 years	Clear	UO	Saline
R8	150	6 years	Clear	UO	Saline
R9	350	1 years	Clear	UO	Saline
R10	12	5 years	Clear	UO	Saline
R11	350	2 years	Clear	UO	Saline
R12	18	3 years	Clear	UO	Saline
R13	20	4 years	Clear	UO	Saline
R14	22	5 years	Clear	UO	Saline
R15	25	15 years	Clear	UO	Saline
R16	120	1 years	Clear	UO	Saline
R17	17	7 years	Clear	UO	Bitter
R18	21	2 years	Clear	UO	Saline
R19	15	3 years	Clear	UO	Saline
R20	14	4 years	Clear	UO	Saline

UO (Un objection)

Table 3: Physical characteristics of groundwater quality of Orangi Town.

Sample code	TDS (ppm)	T (°C)	EC (µS/cm)	pH	Turbidity (NTU)	Hardness (mg/L)
R1	4360	26.2	6812.5	6.26	0	2400
R2	13600	25.8	21250	6.59	0	7800
R3	1250	26	1953.12	7	0	1000
R4	14800	26.1	23125	6.67	0	4800
R5	2050	26.1	3203.12	6.98	0	2200
R6	6480	26.1	10125	7.13	0	3800
R7	7130	26	11140.6	6.96	0	3600
R8	13300	26	20781.3	6.52	0	6800
R9	3560	26.1	5562.5	6.53	0	1600
R10	1810	26.2	2828.12	6.77	0	1400
R11	4750	26.3	7421.87	6.77	0	3000
R12	2750	26.4	4296.87	6.86	0	800
R13	2070	26	3234.37	6.76	0	1400
R14	1940	26.4	3031.25	6.84	0	1600
R15	5670	26.5	8859.37	5.67	0	2600
R16	5450	26.5	8515.62	6.8	0	3400
R17	5610	26.3	8765.62	7.29	0	3000
R18	6760	25.8	10562.5	7.02	0	3200
R19	6550	25.8	10234.4	7.16	0	1800
R20	2490	25.1	3890.62	7.23	0	2600

Table 4: Classification of water based on TDS values.

No of samples	Standard values of TDS (mg/L)	Name
-	0-1,000	Fresh
17	1,000-10,000	Brackish
3	10,000-100,000	Saline
-	> 100,000	Brine

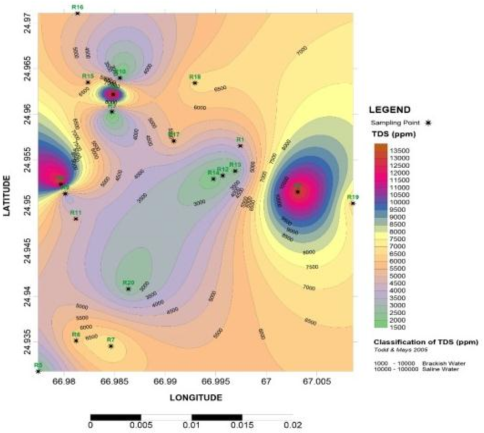

Figure 3: Isopach map showing the classification of TDS based on water quality in the study area.

Table 5: Chemical Characteristics of groundwater quality of Orangi Town.

Sample code	Major Cations (mg/L)				Major Anions (mg/L)			
	Mg^{2+}	Ca^{2+}	K^+	Na^+	SO_4^{2-}	HCO_3^-	NO_3^-	Cl^-
R1	194	640	12	998	1565	240	10.11	992
R2	1530	600	33	1200	3293	200	9.76	4751
R3	190	88	11	662	572	300	7.50	70
R4	802	600	25	3398	2675	420	1.21	10779
R5	427	177	16	796	969	380	9.99	780
R6	680	400	15	1083	2791	580	8.81	3262
R7	551	533	31	1172	1707	360	8.94	4042
R8	867	933	19	2897	2485	480	13.34	8935
R9	173	355	25	865	1138	480	14.23	1489
R10	233	177	21	765	595	480	21.73	567
R11	365	600	16	300	1347	380	11.32	2340
R12	97	160	21	498	78	440	11.54	1205
R13	151	311	30	436	183	400	20.80	709
R14	281	177	29	401	149	440	20.93	638
R15	146	800	42	978	1790	440	24.86	2907
R16	437	640	27	996	1294	520	31.98	2340
R17	437	480	36	955	1400	420	10.66	2340
R18	486	480	46	897	1148	380	13.29	3475
R19	6.1	710	30	812	1001	300	27.11	3546
R20	243	640	29	910	968	440	7.04	921

Table 6: Comparison and descriptive statistical analysis of the studied environment.

Parameters	Unit	Min	Max	Average	(WHO, 2011)	EPA Maximum Contamination Level (MCL)
TDS	(ppm)	1250	14800	5619	500	500
pH	-	5.67	7.29	6.79	6.5-8.5	6.5-8.5
EC	(µS/cm)	1953.12	23125	8779.6	1400	-
Turbidity	(NTU)	0.00	0.00	0.00	5.00	-
Hardness	(mg/L)	800	7800	2940	300	-
Mg^{2+}	(mg/L)	6.1	1530	414.805	50	-
Ca^{2+}	(mg/L)	88	933	475.05	75	-
K^+	(mg/L)	11	46	25.7	12	-
Na^+	(mg/L)	300	3398	1050.95	200	-
SO_4^{2-}	(mg/L)	78	3293	1238.33	250	250
HCO_3^-	(mg/L)	200	580	404	500	-
NO_3^-	(mg/L)	1.21	31.98	14.2575	50	-
Cl^-	(mg/L)	70	10779	2804.4	250	250
Temperature	(°C)	25.1	26.5	26.085	25	-

Table 7: Correlation matrix of the groundwater samples of Orangi Town.

Parameters	Depth	Temperature	Ca^{2+}	K^+	Na^+	SO_4^{2-}	HCO_3^-	NO_3^-	Cl^-	Mg^{2+}	EC	TDS	pH	Hardness
Depth	1.00													
Temperature	0.08	1.00												
Ca^{2+}	0.06	-0.17	1.00											
K^+	-0.42	-0.12	0.29	1.00										
Na^+	0.06	-0.11	0.51	-0.03	1.00									
SO_4^{2-}	0.47	-0.11	0.61	0.04	0.66	1.00								
HCO_3^-	0.18	0.26	-0.07	-0.02	0.12	-0.07	1.00							
NO_3^-	-0.32	0.37	0.12	0.31	-0.35	-0.35	0.22	1.00						
Cl^-	0.14	-0.07	0.61	0.14	0.92	0.73	0.051	-0.28	1.00					
Mg^{2+}	0.31	-0.17	0.31	0.08	0.53	0.81	-0.17	-0.38	0.62	1.00				
EC	0.17	-0.11	0.65	0.2	0.82	0.85	-0.14	-0.27	0.94	0.79	1.00			
TDS	0.17	-0.11	0.65	0.2	0.82	0.85	-0.14	-0.27	0.94	0.79	1.00	1.00		
pH	0	-0.42	-0.36	-0.08	-0.19	-0.24	0.09	-0.23	-0.16	-0.02	-0.2	-0.2	1.00	
Hardness	0.27	-0.2	0.62	0.14	0.65	0.88	-0.14	-0.27	0.75	0.93	0.89	0.89	-0.16	1.00

Table 8: WHO standard (Vs) and unit weight (Wn) for the following parameters.

Parameters	WHO Standard (Vs)	1/Vs	K (Constant)	Unit weight Wn=K/Vs
PH	8.5	0.11765	2.9	0.34118
Hardness (mg/L)	300	0.00333	2.9	0.00967
TDS (mg/L)	500	0.002	2.9	0.0058
HCO_3^- (mg/L)	500	0.002	2.9	0.0058
NO_3^- (mg/L)	50	0.02	2.9	0.058
K^+ (mg/L)	12	0.08333	2.9	0.24167
Na^+ (mg/L)	200	0.005	2.9	0.0145
Mg^{2+} (mg/L)	50	0.02	2.9	0.058
Ca^{2+} (mg/L)	75	0.01333	2.9	0.03867
Cl^- (mg/L)	250	0.004	2.9	0.0116
SO_4^{2-} (mg/L)	250	0.004	2.9	0.0116
∑Wn = 0.80				

Table 9: Calculations of water quality index (WQI) for the groundwater in Orangi Town.

Parameters	WHO Standard (Vs)	Observed value (Vn)	Ideal value (Vi)	(Vn-Vi)	(Vs-Vi)	Quality rating Qn= (Vn-Vi/Vs- Vi)×100	Unit weight (Wn =K/Vs)	(Qn×Wn)
PH	8.5	6.79	7	-0.21	1.5	-14	0.34	-4.78
Hardness (mg/L)	300	2940	0	2940	300	980	0.01	9.47
TDS (mg/L)	500	5619	0	5619	500	1123.8	0.01	6.52
HCO_3^- (mg/L)	500	404	0	404	500	80.8	0.01	0.47
NO_3^- (mg/L)	50	14.2575	0	14.2575	50	28.515	0.06	1.65
K^+ (mg/L)	12	25.7	0	25.7	12	214.167	0.24	51.76
Na^+ (mg/L)	200	1050.95	0	1050.95	200	525.475	0.01	7.62
Mg^{2+} (mg/L)	50	414.805	0	414.805	50	829.61	0.06	48.12
Ca^{2+} (mg/L)	75	475.05	0	475.05	75	633.4	0.04	24.49
Cl^- (mg/L)	250	2804.4	0	2804.4	250	1121.76	0.01	13.01
SO_4^{2-} (mg/L)	250	1238.333	0	1238.33	250	495.333	0.01	5.75
							∑Wn = 0.7933	∑QnWn = 164.08
WQI = 206.83								

Table 10: Types of water according to WQI (Sahu & Sikdar, 2008)

Range	Type of water
< 50	Excellent water
50-100.1	Good water
100-200.1	Poor water
200-300.1	Very poor water
> 300	Water unsuitable for drinking

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