Research Article

BIOMEDICAL Journal of Scientific & Technical Research

ISSN: 2574 -1241

DOI: 10.26717/BJSTR.2025.63.009848

Groundwater Dynamics in Karachi: Comparative Analysis of More than Two Decades of Extraction, Quality Changes, and Seawater Interruption in Water-Table

Yasmin Nergis[1], Mughal Sharif[1], Ahmed Jamil[1]*, Naeem Ahmed Mughal[2] and Waqar Ahmed[3]

[1]*Environmental Research Centre Bahria University Karachi Campus, Pakistan*

[2]*Sindh Environmental Protection Agency Govt. of Sindh Korangi Industrial Area, Pakistan*

[3]*Institute of Environmental Studies University of Karachi, Pakistan*

***Corresponding author:** Ahmed Jamil, Environmental Research Centre Bahria University Karachi Campus, Karachi-Pakistan

ARTICLE INFO

Received: August 18, 2025

Published: September 03, 2025

Citation: Yasmin Nergis, Mughal Sharif, Ahmed Jamil, Naeem Ahmed Mughal and Waqar Ahmed. Groundwater Dynamics in Karachi: Comparative Analysis of More than Two Decades of Extraction, Quality Changes, and Seawater Interruption in Water-Table. Biomed J Sci & Tech Res 63(1)-2025. BJSTR. MS.ID.009848.

ABSTRACT

The study area is located in a dry climate zone by very slight precipitation due to out of main monsoon path. Topography of research area doesn't support orographic (mountain-driven) rainfall. Consequently, as indicated that the research study is Karachi metropolitan area. In addition, in study area open drainage system exists includes many nallahs (municipal water drainage streams) with inappropriate conditions which flows southwest across urban areas of Karachi. Previously, research was carried out in 2000 by the collection of groundwater samples for both quality and quantity analysis including physical parameters like TDS, pH, EC, and Sodium Adsorption Ratio (SAR), along with macro ionic species such as Na, K, Ca, Mg, Cl, HCO3, and SO4. Now, to focus groundwater dynamics after more than two decades in the end of 2022, once more correspondingly sampling repeated through follow the previous pattern and methods. Remarkable results are derived to understand the groundwater's suitability for domestic purposes including the existing state also depth of water-table. The study found that the water shortage in Karachi was around 630 million gallons per day (MGD) from 1961 to 1998, based on a population of about 15 million. From 2005 to 2020, this water shortage increased up to 1,102 MGD by an additional 472 MGD as the population increased up to 27 million. Currently, Karachi residents rely on groundwater and water from reverse osmosis (RO) plants, which also pull up from groundwater. By the end of 2025, with a predictable population of 32 million, the water shortage can be increased by 1,300.3 MGD. This speedily rising demand will make cause of excess salinity range in groundwater, beside this the water-table may fall further from 400 feet to 1,000 feet below from the surface. In lower-lying areas of Karachi, over-exploitation of groundwater could make reason of seawater intrusion and in result worsening the quality of water for Karachi metropolitan.

Keywords: Groundwater; Quality; Water-Table; Seawater Interruption

Introduction

This study took an efficient methodology to appraise the geochemical characteristics of shallow groundwater in Karachi, where the water-table was between 30 to 50 feet deep in 2000 (Nergis, et al. [1]). Aim of this study was to find out condition of underground bedrock and climate impact the distribution of different elements in this groundwater. The study also aimed to assess the compatibility of shallow groundwater for drinking, irrigation, and other purposes including identifying potential health risks. The findings were first published in 2003 (Shahid, et al. [2]) and later updated in 2015 (Adnan S, et al. [3]). The drainage system in Karachi has many small streams that flow southwest across the city (Nergis, et al. [4]). Mostly, the municipal sewage, industrial waste, poultry farms including agriculture runoff from and auto industries are carried by these streams. As a result, the condition of shallow groundwater in considered zone has been heavily impacted (Shahid, et al. [2]).

 DOI: 10.26717/BJSTR.2025.63.009848

Saltwater Intrusion

A particular words combination as "excess salinity range in groundwater" mostly occurs when saltwater moves into freshwater areas within an aquifer. This is mainly caused by the overuse of large-capacity wells, including those for industrial, agricultural, and public use. Other long-term causes can include extended droughts and rising sea levels (KDP 1961 [5], & KSDP 2020 [6,7]). In the Karachi aquifer, saltwater intrusion was monitored in several high-capacity industrial and public wells between 2015 and 2020, due to concerns about increased water demand pulling in saltwater (Figure 1).

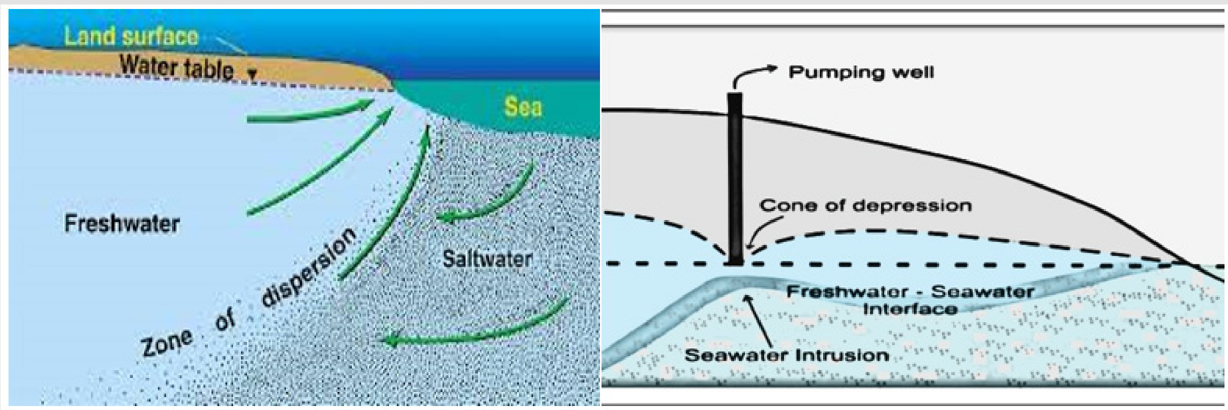

Figure 1: Groundwater flow patterns showing saltwater intrusion (P Prusty, et al. [8]).

Hydrological Drilling of Four Basin of Karachi Data by Geological Survey of Pakistan

According to the Geological Survey of Pakistan (GSP 1985 [8]) as shown in below Table 1 [9], four basins in Karachi have been described based on hydrological drilling data. The Thano Bula Khan basin covers an area of 3,600 square kilometers, with a water-table ranging from 5.7 to 15.5 feet. The water is found in the Upper-Nari Sandstone formation at depths of 160–200 feet. This basin contains 300 shallow wells and one tube well, providing a total water quantity of 780 million gallons. The water is slightly brackish and is used for both domestic and irrigation purposes, supplying approximately 6,000 users. The Kalu Khuhar basin spans 1,000 square kilometers, with a Water-table depth of 10 - 13 feet. The east side of the basin consists of the Laki formation, while the southwest side is drained by the Nadi and contains Nari fine sand. There are only a few wells in this basin, with water levels ranging from 62 to 78 feet from the ground. The water quality is slightly brackish, and it primarily consists of seepage water, causing wells to dry up in the summer. The Malir basin covers 1,520 square kilometers, with a water-table depth ranging from 24 to 75 feet. The geological formations in this basin include Gaj alluvium, aeolian deposits, and limestone. There are 450 wells in this region, providing a total water quantity of 1,394 million gallons. The water is brackish, particularly near Khade Ji Nadi, and is primarily used for irrigation, supporting approximately 1,200 users. Lastly, the Gadap basin extends over 510 square kilometers, with a water-table depth of 24-100 feet. The underlying formation consists of Gaj sandy limestone and sandstone. This basin contains 50 wells, including 24 designated for irrigation, with a total water supply of 780 million gallons. The water is slightly brackish, and its usage ranges between 200-500 users (GSP [10]). This data provides a historical image of Karachi's groundwater resources in 1985, highlighting water availability, quality, and usage across four basins. It shows varying water-table depths, slightly brackish to brackish water quality, and its primary use for domestic and irrigation purposes. The findings reflect the region's hydrological conditions and the dependence on wells and tube wells for water supply.

Table 1: Hydrological Drilling Data by Geological Survey of Pakistan (GSP 1985).

Sr. No:	Basin	Area sq.km	Water-Table (Feet)	Formation	Shallow well / Tube well	Quantity Million Gallons	Quality of water	Uses Domestic / Irrigation
1	Thano Bula Khan	3,600	5.7-15.5	Upper-Nari Sandstone (160-200 feet)	300/1	780	Slightly Brackish	6000 for Both
2	Kalu Khuhar	1000	10-13	Laki (east side) Nadi drained SW (Nari fine Sand)	Few	62-78 (feet from ground)	Slightly Brackish	Seepage water (well dry up in summer)
3	Malir	1,520	24-75	Gaj (Alluvium & Aeoli-an) and limestone	450	1,394	Brackish (Near khade ji Nadi)	For Irrigation 1200
4	Gadap	510	24-100	Gaj (Sandy limestone and Sandstone	50 (24 irrigation)	780	Slightly Brackish	200-500

Tendencies in Population Growth and Water Demand in Karachi

Karachi conducted population surveys in 1961, 1972, 1981 and 1998, with the annual growth ratios shown in Table 2 (KDP [6]). The population was adjusted to 9.96 million according to the Karachi Strategic Development Plan (KSDP [6]), based on the 1998 census data.

Table 2: Annual Growth Rate of Karachi from 1961 to 1998.

<table>
<tr><th colspan="6">Annual Growth Rate Karachi Development Plan 2000</th></tr>
<tr><th>Years</th><th>%</th><th>(x 1000)</th><th>Population Growth</th><th colspan="2">Total population of Karachi</th></tr>
<tr><td>1961</td><td>--</td><td>1,912.60</td><td rowspan="4">9.422 million (1961 to 1998)</td><td rowspan="4">630 MGD (KW&SB end of 2006)</td><td rowspan="4">Adjusted by Karachi Strategic Development Plan 2020 based on 1998 census data</td></tr>
<tr><td>1972</td><td>5.5</td><td>3,498.60</td></tr>
<tr><td>1981</td><td>4.8</td><td>5,395.40</td></tr>
<tr><td>1998</td><td>4.5</td><td>11,335.00</td></tr>
</table>

KSDP 2020

According to the Karachi Strategic Development Plan (KSDP 2020) August 2007, shown in Table 3, the population of Karachi was projected to grow significantly over the years. In 2005, the population was 15.120 million, increasing to 18.529 million in 2010, 22.594 million in 2015, and reaching 27.55 million by 2020. Correspondingly, the per capita bulk water demand, based on Japan International Cooperation Agency (JICA) estimates, rose from 16.0 Gallon per capita demand (GPCD) in 2005 to 18.0 GPCD in 2010, 20.0 GPCD in 2015, and 22.0 GPCD in 2020. As a result, the bulk water demand also increased, rising from 604.8 MGD in 2005 to 741.1 MGD in 2010, 903.8 MGD in 2015, and ultimately reaching 1,102.0 MGD in 2020. However, water loss percentages showed a decreasing trend, dropping from 35.0% in 2005 to 33.0% in 2010, 28.5% in 2015, and further down to 21.5% in 2020.The total water supply to customers was recorded at 357.4 MGD in 2005, which increased to 451.4 MGD in 2010, 587.4 MGD in 2015, and 786.4 MGD in 2020. Within this, domestic water consumption accounted for 214.4 MGD in 2005, rising to 272.6 MGD in 2010, 362.3 MGD in 2015, and reaching 497.3 MGD in 2020. Meanwhile, non-domestic consumption followed a similar upward trend, increasing from 143.0 MGD in 2005 to 178.8 MGD in 2010, 225.1 MGD in 2015, and 289.1 MGD in 2020. As given in Table 3, data highlights the increasing pressure on Karachi's water resources due to rapid population growth from 2005 to 2020. It shows a rising trend in bulk water demand and consumption, while efforts to reduce water loss have improved efficiency. However, despite increased supply, the growing gap between demand and availability underscores the challenges in meeting the city's water needs (Figure 2).

 DOI: 10.26717/BJSTR.2025.63.009848

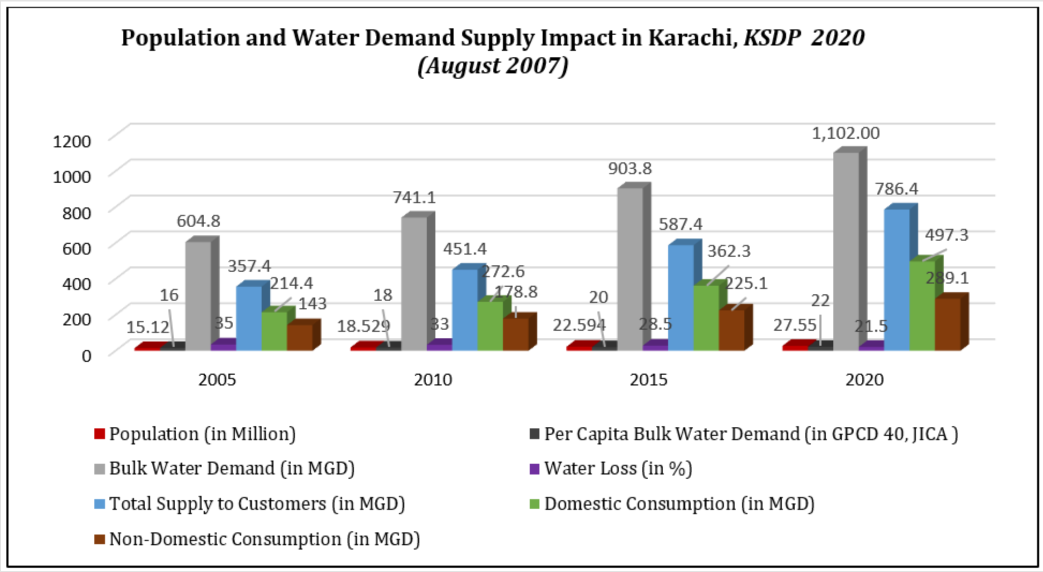

Figure 2: Graph Showing Population and Water Demand Supply Gape of Karachi.

Table 3: Population and Water Demand Supply Impact in Karachi, KSDP 2020.

Sr. No:	Parameters	Units	2005	2010	2015	2020
1.	Population	Million	15,120	18.529	22.594	27.55
2.	Per Capita Bulk Water Demand	GPCD 40 (JICA)	16	18	20	22
3.	Bulk Water Demand	MGD	604.8	741.1	903.8	1,102.00
4.	Water Loss	%	35.00%	33.00%	28.50%	21.50%
5.	Total Supply to Customers	MGD	357.4	451.4	587.4	786.4
6.	Domestic Consumption	MGD	214.4	272.6	362.3	497.3
7.	Non-Domestic Consumption	MGD	143	178.8	225.1	289.1

Plans for Managing Water Demand

In 2005, Karachi's population was 15.2 million (KSDP [6]). Projections estimated that by 2020, the population would reach 27.5 million; and by the end of 2025, it could grow to 32.0 million- almost double the 2005 population. However, the potential increase in water supply capacity during this period is only about 630 MGD, which is less than the current supply capacity of 1,300 MGD (see Tables 4 & 5). These figures indicate that Karachi will likely face severe water shortages through 2025.

Table 4: Annual Growth Rate and Water Demand of Karachi from 2005-2025.

Population of Karachi Projected in % by KSDP - 2020 (August 2007) and 2025 Projected by JICA						
Years	%	(x 1000)	Population Growth	Bulk water supplies	Total of population	Per Capita Demand
2005	4.2	15,120.00	45% population (2005 to 2020) in three towns located on the outskirts of the Karachi City (Keamari, Gadap and Bin Qasim).55% occur in remaining 15 towns.	Capacity of existing water sources 630 MGD (KW&SB end of 2006)	15.12 million (2006)	Per capita bulk water demand in 2006 was calculated by dividing actual supply amount of 630 MGD of 15.12 million as follows: 630 MGD 15.8 million = 39.9 gallons/capita/day (181.3LPCD) or (GPCD)
2010	4.15	18,529.00				
2015	4.05	22,594.00				
2020	3.36	27,550.00				
2025	3.36	32,506	Severe water constraints over the planning horizon of 2025	Demand 1,300 MGD	Will be 32.0 million	40 GPCD at the end of 2025 is as much as the present demand (as of 2006) JICA

 DOI: 10.26717/BJSTR.2025.63.009848

Table 5: Bulk Water Sources and Demand for Karachi.

Bulk Water System	Actual Supply in MGD	Water demand In MGD (2020)	Ground Water Sources (2025) in MGD
GK System	300	1,102.0 - 630 = 472.2	1,300.3 - 630 = 670.3
Haleji System	30		
K-II System	120		
K-III System	100		
Dumlottee Wells	---		
Hub System	80		
Total	630	472.2	670.3

Methodology and Analytical Methods

A total of 20 water samples were collected in pre-cleaned plastic bottles. Prior to sampling, bore water was purged for one minute to ensure representative sample collection. On-site measurements of total dissolved solids (TDS) and pH were conducted using HACH meters. Chloride (Cl^-) and bicarbonate (HCO_3^-) concentrations were determined through titration, while sulfate (SO_4^{2-}) analysis was performed using a HACH spectrophotometer 2800 at the Environmental Research Centre Bahria University Karachi Campus. Major cations, including calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), and potassium (K^+), were quantified using an atomic absorption spectrophotometer (AAS Thermo Scientific ICE 3500) at ERC, BUKC. All analyses adhered to standard testing methods (STM) to ensure accuracy and reliability (Figure 3).

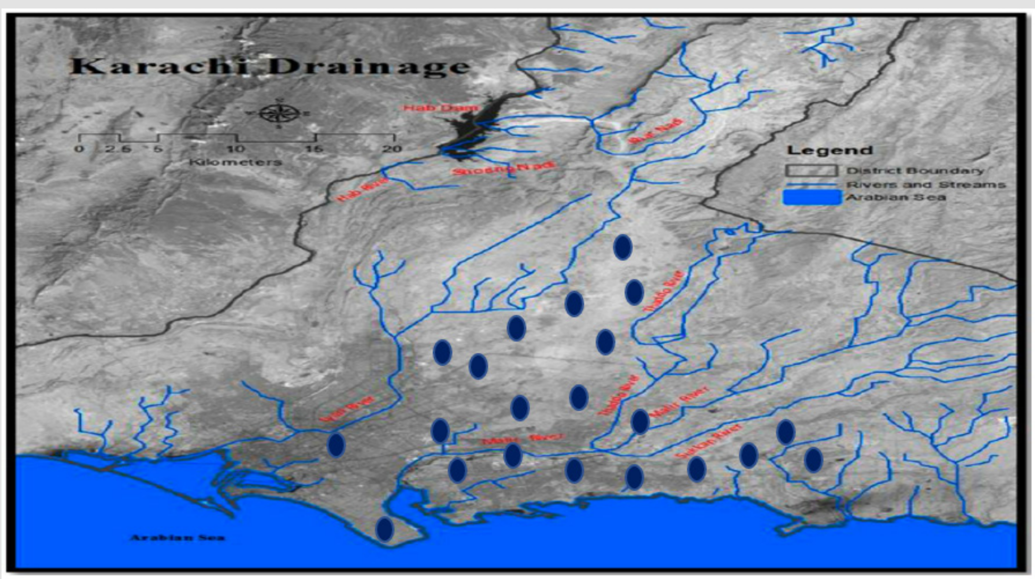

Figure 3: Showing Sampling Location of Karachi in 2000 and 2022.

Result and Discussion

The previous study was conducted in 2000 and published by Hamdard Medicos in 2003, now current assessment was carried out in 2022 at previously same locations in the same approach for comparative analysis to evaluate current and previous condition of groundwater after two decades. It examines the historical trends in groundwater quality and quantity and assesses future water requirements for Karachi's population at end of 2025. As given below Table 6 compares the physical parameters of groundwater quality in Karachi over the past 20+ years. During this period, the depth of the groundwater has increased, ranging from 50 to 500 feet, while Total Dissolved Solids (TDS) have risen from 3,900 to 10,945 ppm, and the Electrical Conductivity (EC) has increased from 4.65 to 19.2 ms/cm. The Sodium Adsorption Ratio (SAR) has remained relatively stable. The results show that the water-table has been dropping by 20-25 feet annually, and TDS levels continue to rise. In 2000, the water-table ranged from 30 to 60 feet, while by 2022, it had deepened to between

80 and 500 feet. By end of 2025, it is expected to range from 500 to 800 feet. Stable aquifers were found in the Malir basin, with Hydrological Drilling Data from Karachi (GSP, 1985) indicating a well depth of 500 feet. The source of this underground water is partly due to percolating rainwater and mainly from leaks in faulty water distribution network and drainage pipelines in the past. Urban water supply in Karachi comes from the Indus and Hub river channels. The water samples analysed show that the water quality is within the limits according to standards of WHO. As showing in Figure 4, the percentage increase or decrease for each parameter from the year 2000 to 2022:

a) **Depth:** Increased from **30–50 feet** in 2000 to **60–500 feet** in 2022.

1. The minimum depth increased by **100%** (from 30 to 60 feet).
2. The maximum depth increased by **900%** (from 50 to 500 feet).

b) **pH:** Increased from **6.8–7.4** to **7.19–7.78** (a slight rise, around **5% increase** on average).

c) **TDS:** Increased from **240–3,900 ppm** to **3,107–10,945 ppm**.

3. The minimum TDS increased by **≈1,195%** (from 240 to 3,107 ppm).
4. The maximum TDS increased by **≈180%** (from 3,900 to 10,945 ppm).

d) **EC:** Increased from **0.36–4.65 ms/cm** to **5.4–19.2 ms/cm**.

5. The minimum EC increased by **1,400%** (from 0.36 to 5.4 ms/cm).
6. The maximum EC increased by **313%** (from 4.65 to 19.2 ms/cm).

e) **SAR:** Slightly decreased from **10–24** in 2000 to **9.13–17.83** in 2022, indicating an **8.7–25.7%** reduction.

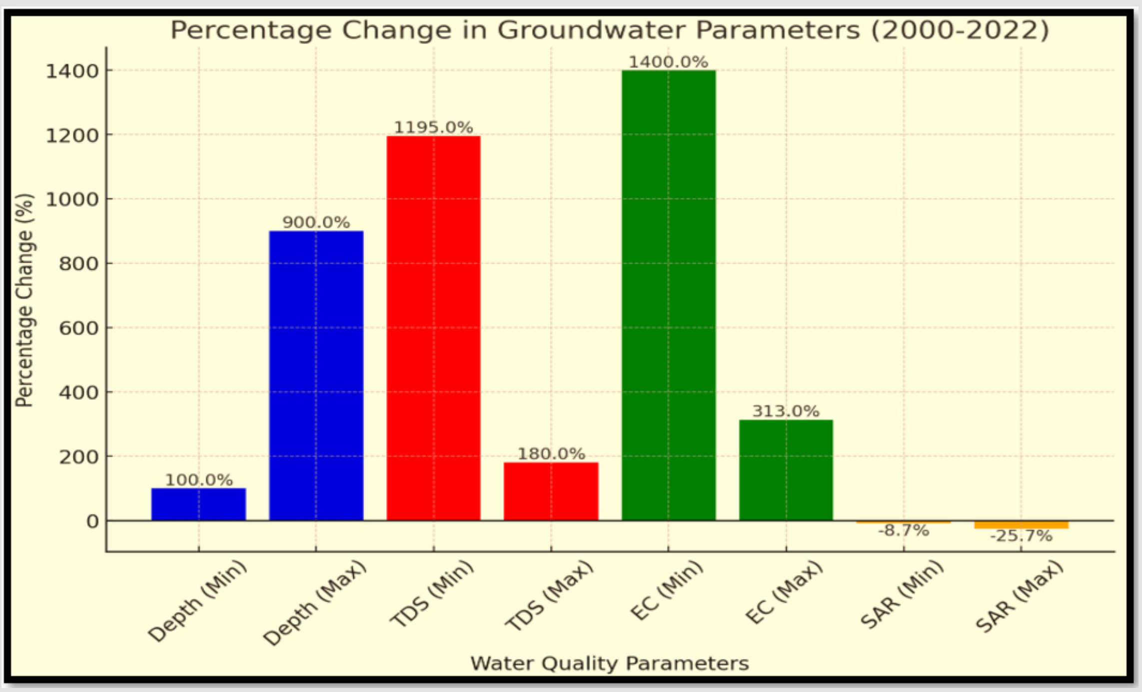

Figure 4: Showing Changes in Groundwater Parameters in Percentage (2000-2022).

Table 6: Showing Comparison and Forecast Analysis of Ground Water Quality Differentiates by Last 20+ Years Gaps.

Sr. No:	Parameter	Units	In Year 2000	In Year 2022	At the End of Year 2025 (Predicted Values)	Annually Increase
1	Depth	Feet	30-50	60-500	500-800	15-20
2	PH	---	6.8-7.4	7.19-7.78	---	3.63
3	TDS	ppm	240-3900	3107-10945	19595-20000	3919
4	EC	ms/cm	0.36-4.65	5.4-19.2	---	0.73
5	SAR	---	10-12	9.13-17.83	---	---

DOI: 10.26717/BJSTR.2025.63.009848

Table 7 illustrates the deterioration in groundwater quality between the years 2000 and 2022, particularly in terms of increasing ion concentrations. The data shows a significant rise in both cation (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) and anion (Cl^{-}, SO_4^{2-}, HCO_3^{-}) concentrations, indicating increasing salinity and potential contamination over time (Figures 5 & 6).

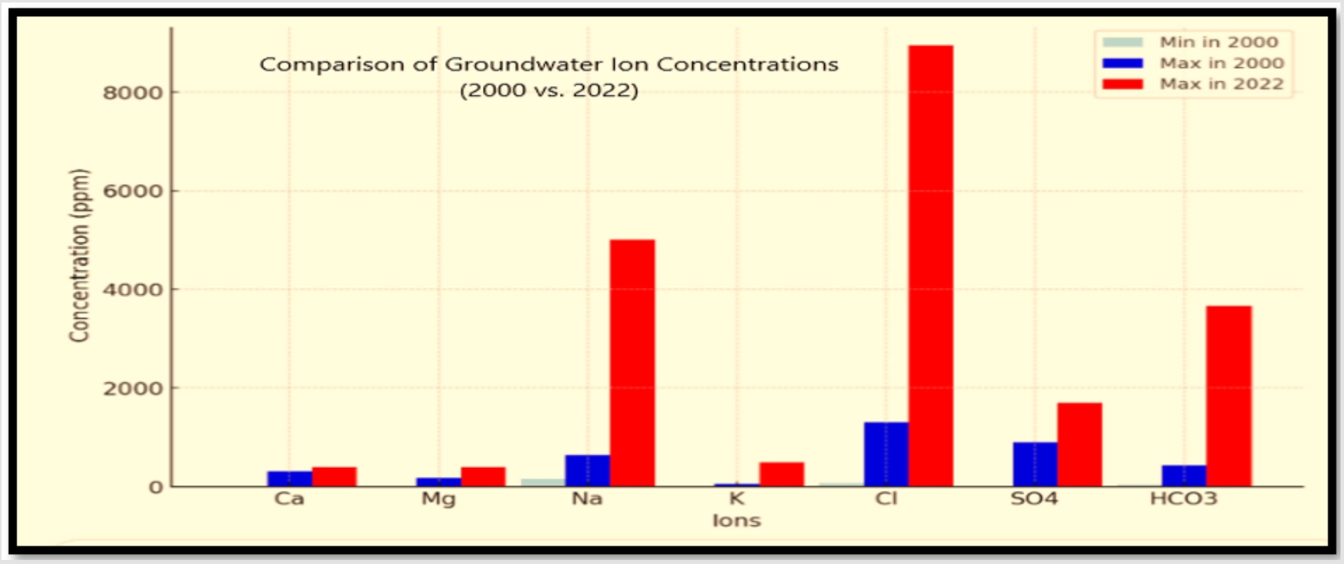

Figure 5: Showing Comparison of Groundwater Ions Concentrations (2000-2022).

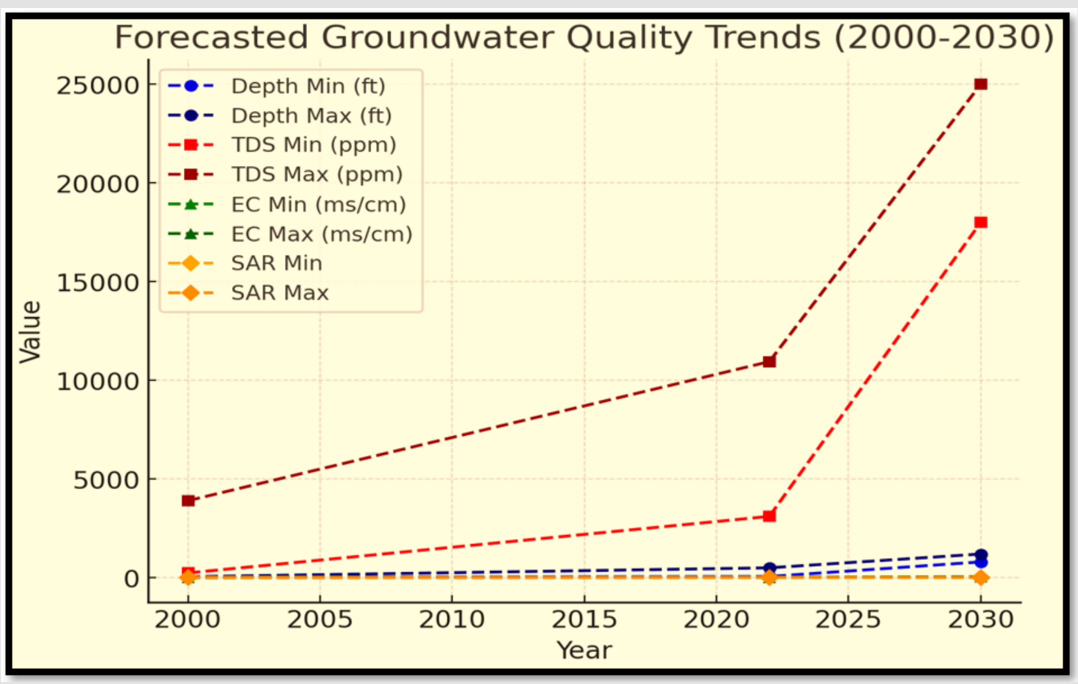

Figure 6: Showing Forecasted Groundwater Quality Trends (2000-2030).

Table 7: Showing Comparison of Cations and Anions of Ground Water Quality Differentiates by Last 20+ Years Gaps.

Sr. No:	Parameters	Ions	Units	In 2000	In 2022
1	Ca	Cation	ppm	15-305	81-400
2	Mg			5-170	24-400
3	Na			150-640	1210-5014
4	K			10-55	25-492
5	CL	Anion		70-1300	1891-8946
6	SO_4			5-900	59-1704
7	HCO_3			40-425	610-3660

Key Observations

a) Calcium (Ca^{2+}) and Magnesium (Mg^{2+}): Increased substantially, suggesting higher mineral dissolution in groundwater.

b) Sodium (Na^+) and Potassium (K^+): Show a drastic rise, particularly sodium, which has increased up to 7-8 times, indicating severe salinization.

c) Chloride (Cl^-): Increased by up to 7 times, a sign of saltwater intrusion or anthropogenic contamination.

d) Sulfate (SO_4^{2-}) and Bicarbonate (HCO_3^-): Show significant increases, suggesting potential industrial, agricultural, or geochemical influences on groundwater quality.

This forecast analysis graph illustrates the projected trends in groundwater quality parameters from 2000 to 2030. It shows a significant increase in depth, TDS, and EC, indicating worsening water quality, while SAR values are gradually decreasing. If current trends continue, groundwater conditions could become increasingly unsuitable for domestic and agricultural use.

Conclusion

The majority of the urban and suburban population relies on groundwater for various uses, excluding drinking. Hence, this study concludes that Karachi has been facing a water scarcity of 472.2 MGD since 2020. By the end of 2025, the water shortage in Karachi is expected to reach 1,300.3 MGD. As a result, water quality will likely become more brackish, and the water-table will continue to drop. The lower-lying areas of Karachi are at risk of saltwater disruption due to the over-drawing-out of aquifer. The data clearly indicates a significant deterioration in groundwater quality over the years, with TDS, EC, and depth increasing severely, making water more saline and less suitable for use. The water-table has also dropped significantly, posing serious concerns for future water availability.

The data also reflects a major decline in groundwater quality over the past two decades, with increasing salinity, hardness, and contamination risks. These trends could have serious implications for agricultural, industrial, and drinking water use in the affected areas. Excessive groundwater extraction can lead to land subsidence and alter subsurface stress conditions, which may activate fault lines and trigger localized seismic activity. Additionally, the resulting surface deformation can enhance sediment accumulation in affected areas as stated in previous study by (Kakar, et al. [11,12]). Beside this, the health impact of brackish water has been observed on skin in the form of allergies, hair loss, eye irritation, and other issues. Additionally, the deteriorating sanitary system is causing damage, with both private and public sectors facing significant economic consequences.

Recommendation

- A comprehensive water management system should be implemented to ensure efficient use and distribution of available water resources.
- Water conservation efforts can be enhanced through the installation of water meters to monitor and control consumption.

A strict groundwater extraction policy should be enforced to prevent the misuse of groundwater and ensure its sustainable use for future generations.

References

1. Nergis Y, Sharif M, Ahmed W (2007) Potable water as Sources of Heavy Metals in, the blood of Neuro Patients of Karachi Pakistan. Journal of Chemical Society of Pak 29(1): 86-93.
2. Shahid N, Nergis Y, Sheikh SA (2003) Geochemistry and quality of groundwater of Karachi. Hamdard of Medicus 46(1): 1-9.
3. Adnan S, K Ullah, S Gao (2015) Characterization of drought and its assessment over Sindh, Pakistan during 1951–2010. Journal of Meteorological Research 29(5): 837-857.
4. Nergis Y, Ahmed I, Sharif M (2005) Impact of Contaminated Vegetable, Fruits & Fodder on Human Health, by Malir River Farms, Karachi. Journal of Chemical Society of Pak 27(6): 561.
5. (1961) KDP (1961, 1972, & 1981): Karachi Development Plan 2000. Government of Sindh.
6. (2020) KSDP. Karachi Strategic Development Plan 2020. Government of Sindh.
7. GSP (1985) Hydrological Drilling of Four Basin of Karachi Data by Geological Survey of Pakistan.
8. P Prusty, SH Farooq (2020) Seawater intrusion in the coastal aquifers of India - A review. Hydro Research 3: 61-74.
9. (2012) GSP 2012 Geological Map of Sindh, Pakistan: Geological Survey of Pakistan, Quetta, Pakistan.
10. Kakar DM, Babar M, Khuhawar MY, Qureshi AL (2020) Groundwater depletion and land subsidence in Sindh Province, Pakistan. Journal of Earth Sciences & Environmental Studies 5(3): 55-62.
11. Syed Anisuddin Ahmed. Tauqir Ahmed Shuja (1985) Pumping Tests Results of Thano. Bula Khan, Kalukhuhar, Upper Malir. (Khadeji and Kathore areas) Geological Survey of Pakistan, pp. 117.

ISSN: 2574-1241

DOI: 10.26717/BJSTR.2025.63.009848

Ahmed Jamil. Biomed J Sci & Tech Res