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Hydrochemical assessment of groundwater quality in the coastal belt of Sindh, Pakistan: Implications for human health

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Abstract

The study evaluates the groundwater quality of the Sindh coastal belt, examining pre- and post-monsoon variations across multiple sampling points from Badin to Karachi. A total of 32 groundwater samples were analyzed for key physicochemical parameters, including pH, Electrical Conductivity (EC), Total Hardness (TH), Total Dissolved Solids (TDS), turbidity, calcium hardness, magnesium hardness, sulfates, and chlorides. The results reveal significant contamination attributed to industrial discharges, agricultural runoff, and direct wastewater disposal into the Arabian Sea. Comparisons with WHO standards highlight elevated levels of dissolved solids and hardness, which pose risks to both human health and ecosystem stability.

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Introduction

With the Indus River to the east and the Hub River to the west, Sindh's coastline, which stretches into the northern Arabian Sea, is home to some of the most beautiful beaches, especially in Karachi [1, 2]. The coast of Karachi is divided into two parts: the eastern part, which includes the beaches of Clifton, Gizri, and Ibrahim Haidari, and the western part, which stretches from Manora Island to Cape Monze and beyond to the Makran coast [3].

The environmental quality of Karachi's coastal region is of critical concern due to its essential role in ecological stability, public health, and the provision of life-supporting resources such as water [4]. Freshwater, vital for sustainable development, faces increasing threats from pollution, particularly in heavily industrialized and densely populated areas [5, 6]. In Karachi, water bodies are severely impacted by sewage, industrial effluents, and agricultural runoff, leading to significant alterations in their chemical and physical composition, thereby exacerbating the global challenge of water quality degradation [7].

Pollutants such as silt, hazardous chemicals, and excess nutrients can degrade water quality, leading to issues like eutrophication, where nutrient overload triggers algal blooms that deplete oxygen and harm aquatic ecosystems [8]. Additionally, groundwater, vital for agriculture and drinking, is increasingly vulnerable to contamination from industrial discharges, over-extraction, and runoff containing pesticides and fertilizers, jeopardizing both ecosystems and dependent communities [9, 10].

Groundwater quality is influenced by both natural and anthropogenic factors, with nearby geological formations often contributing heavy metals such as lead and arsenic [11]. Excessive groundwater extraction, particularly for agricultural purposes, disrupts the natural balance, increasing the risk of seawater intrusion and further contamination. Agricultural activities exacerbate the issue as fertilizers and chemicals seep into the water table, altering their physical and chemical properties and rendering it unsuitable for drinking and other uses [8].

The aim of the study is to assess the physical and chemical properties of groundwater along the coastal belt of Sindh and compare these findings with World Health Organization (WHO) standards to identify pollution levels, highlight immediate concerns about water safety, and underscore the need for effective water management to protect public health and preserve coastal ecosystems in Karachi and surrounding areas.

Materials and Methods

Study area and sampling points

A total of 64 Groundwater samples during pre-monsoon and post-monsoon seasons were collected along the coastal belt of Sindh (Fig. 1). Triton -200 handheld GPS was used for geolocations.

Sample collection

1-liter polyethylene bottles were used to collect groundwater samples. The bottles were washed with distilled water and rinsed with the sample water before filling and stored according to standard preservation protocols.

Analytical methods

The physical properties of the groundwater samples were evaluated using Hach Sension 156 Portable Multiparameter for pH. EC, TDS, and 2100P Portable Turbidimeter for turbidity on site. Titramatric methods were used for Total Hardness, Calcium (Ca) hardness, and Magnesium (Mg) hardness whereas Sulfates and Chlorides were detected through ion chromatography. All analysis was carried out according to international standards to ensure accuracy and reliability.

Results

pH

The pH of groundwater samples varied from 6.2 to 10.2 and 5.6 to 8.1 during the pre-monsoon and post-monsoon seasons. The recommended range of pH by WHO is 6.5 to 9.2 for drinking water. Some samples in both seasons fall outside the recommended range indicate contamination from industrial and geological sources.

Electrical conductivity (EC)

EC values varied significantly, from 0.61 mS/cm to 48.2 mS/cm in pre-monsoon samples and 0.397 mS/cm to 44.6 mS/cm in post-monsoon samples. Higher conductivity values may be attributed to increased concentrations of dissolved ionic

Table 1: Physical Characteristics and Major Ions Concentration of Groundwater from Different Locations of Coastal Area of Sindh during Pre-monsoon

Sample No.	Name of Locations	Depth	pH	EC	TDS	TH	Turbidity	Cl	SO^{-}_4	Ca^{++}	Mg^{++}
		Feet		$mScm^{-1}$	mg^{-1}	mg^{-1}	NTU	mg^{-1}	mg^{-1}	mg^{-1}	mg^{-1}
1	Badin City	35	7.4	1.38	602	252	2.63	168	27	92	160
2	Qazia Vah	25	6.9	0.87	375	130	0.91	125	12	40	90
3	Golarchi City	43	6.9	4.99	2280	288	0.64	1250	108	220	68
4	Hotel Abdullah Sajawal	30	6.7	1.11	480	115	3.25	212	7	30	85
5	Bagar Mori Thatta	15	6.3	0.61	259	67	0.51	128	4	19	48
6	Hawaks Bay Near Kemari	15	10.2	3.68	1670	359	683	830	66	329	30
7	Ziauddin Hospital, Clifton	40	7.4	17.93	8820	455	4.09	5540	289	108	347
8	Ibrahim Hyderi, Korangi	35	7.1	9.26	4340	463	0.86	2530	155	288	275
9	Nasir Colony, Korangi	35	6.9	2.38	1038	212	0.68	507	14	54	158
10	Mosque Ghosia Rehamania. Landi	35	7	2.49	1091	139	1.94	598	9	53	86
11	Cattle Colony, Shah Latif Town	110	6.3	3.32	1476	277	0.96	680	223	188	89
12	Cattle Colony Milk Farm 1 Shah Latif Town	80	6.7	3.45	1556	226	0.66	835	30	119	107
13	Cattle Coloney Milk Farm 2 Shah Latif Town	150	6.4	3.27	1456	282	0.29	658	24	168	114
14	Al-Shafi Hospital Thatta	40	7.1	4.55	2060	338	1.88	1086	65	210	128
15	Sada Bahar Area, Thatta	25	7.5	2.22	972	208	0.41	545	39	128	80
16	Kinger Lake, Thatta	40	7.5	1.045	450	62	0.22	272	8	38	24
17	Makli Grave Yard, Thatta	60	6.6	5.22	2380	439	0.37	1100	61	410	29
18	Mazar Mai Makli, Thatta	100	6.4	23.81	11930	813	120	7300	543	400	413
19	Shamsi Society, Malir	80	6.8	1.54	668	129	1.51	375	28	80	49
20	Ice Factory, Industrial Area, Korangi	80	6.2	48.2	25000	1436	3.97	10828	1245	440	996
21	Tanree CLeather Factory, Korangi	150	6.2	11.68	5560	383	0.31	3308	278	172	211
22	Attock etroleum, Industrial Area, Landi	80	6.4	2.88	1274	226	1.01	788	32	80	146
23	Habib Chorangi, Sher Shah	60	6.9	1.58	685	120	0.4	480	27	76	44
24	Ismailia Garveyard,Layari	80	6.8	8.14	3800	432	0.38	2095	190	240	192
25	Saddar Karachi, Akbar Road	110	7.2	2.56	1280	377	0.22	586	64	110	267
26	Gulshan-e-Hadeed, Steel Town	200	6.8	10.24	5120	378	0.33	2905	236	156	222
27	Dhabeji city	70	7	3.22	1610	552	0.21	710	44	243	309

28	Gharo City	35	7.3	0.87	435	114	0.23	135	20	54	60
29	MirpurSakro City	40	7.2	1.24	620	154	0.24	238	31	67	87
30	Pak Coast Guard Check Post, Gharho	25	7.2	1.05	525	104	7.86	268	25	48	56
31	Keti-Bandar City	35	7.3	1.58	790	211	10.38	295	30	88	123
32	Thatta City	40	7.5	2.92	1450	324	0.28	635	94	123	201

constituents, indicating pollution from industrial and agricultural activities (**Table 1 & Table 2**).

Total hardness (TH)

TH values ranged between 62-1436 mg/L (pre-monsoon) and 86-558 mg/L (post-monsoon). WHO recommends a TH limit of 200 mg/L; exceeding this may lead to health complications, including kidney issues. The elevated TH in many areas suggests the influence of industrial discharge, solid waste leachates, and natural mineralization.

Total Dissolved Solids (TDS)

TDS concentrations ranged from 259-25,000 mg/L in pre-monsoon and 333-27,300 mg/L in post-monsoon periods, far exceeding the WHO limit of 1000 mg/L in several locations. High TDS levels may result from industrial effluents, household waste, and rock-water interactions, leading to potential gastrointestinal irritation and long-term health risks (**Table 1 & Table 2**).

Turbidity

The turbidity levels ranged from 0.22 to 120 NTU, often exceeding acceptable limits, especially in post-monsoon samples. Turbidity can affect aesthetic quality and indicate the presence of pathogens, thereby reducing the water's potability (**Table 1 & Table 2**).

Major ions (Ca, Mg, SO_4^{2-}, Cl^-)

As indicated in **Table 1 & Table 2** high concentrations of Ca, Mg, SO_4^{2-}, and Cl^- in specific locations reflect contamination from agricultural runoff and industrial effluents. Excess sulfate levels, found in locations near industrial zones, may lead to laxative effects, while elevated chloride levels pose risks for hypertension.

Discussion

The analysis of groundwater samples for key parameters from the Sindh coastal belt to assess water quality and its suitability for different uses as well as to identify potential contamination risk. This analysis reveals an increasing trend in contamination compared to previous studies. Alamgir et al. (2016) [12] and Khuhawar et al. (2019) [13], found moderate levels of EC and TDS, however, the current study indicates that EC and TDS levels have risen, especially in samples from areas adjacent to industrial sites. The high EC levels with increased ionic contents indicate that saline intrusion is becoming a more pressing issue, which is probably being made worse by excessive groundwater extraction and uncontrolled industrial discharges. Additionally, the comparison reveals a concerning rising trend in TDS, which over the previous years suggests a worsening in groundwater quality.

Previous studies found that most groundwater sources in Sindh have a relatively neutral pH range (RRR). However, our current findings reveal significant variability, with some regions showing a shift towards either acidic or basic conditions [14]. This change may result from increased industrial effluent discharge, agricultural runoff, and natural geochemical reactions between water and surrounding minerals. Variations in pH have direct implications for human and agricultural use, impacting the safety of groundwater as a resource and highlighting the potential need for treatment.

Our study's findings on water hardness, particularly concerning calcium and magnesium, are consistent with trends observed in earlier research but indicate an increase in both Ca and Mg hardness. Previous studies, such as those by [15], reported that hardness levels in most areas fell within WHO-recommended limits. However, our analysis identified hardness levels that exceed these safe limits, especially in regions near industrial sites and agricultural fields. While hard water is not directly harmful to health, it

Table 2: Physical Characteristics and Major Ions Concentration of Groundwater from Different Locations of Coastal Area of Sindh during Post-monsoon

Sample No.	Name of Locations	Depth	pH	EC	TDS	TH	Turbidity	Cl	SO^{-}_{4}	Ca^{++}	Mg^{++}
		Feet		$mScm^{-1}$	mg^{-1}	mg^{-1}	NTU	mg^{-1}	mg^{-1}	mg^{-1}	mg^{-1}
1	Badin City	35	7.2	1.24	610	388	0.71	80	18	240	148
2	Qazia Vah	25	6.7	1.195	586	324	0.46	100	8	200	124
3	Golarchi City	43	7.2	4.73	2460	532	0.26	1024	196	360	172
4	Hotel Abdullah Sajawal	30	7.4	0.974	473	183	0.31	95	5	120	63
5	Bagar Mori Thatta	15	7.4	0.397	190.2	86	44.33	38	3	54	32
6	Hawaks Bay Near Kemari	15	8.1	2.62	1310	327	4.14	712	72	249	78
7	Ziauddin Hospital, Clifton	40	8.2	18.73	10600	452	5.57	6800	1229	140	312
8	Ibrahim Hyderi, Korangi	35	6.6	7.89	4200	463	1.01	3030	110	240	196
9	Nasir Colony, Korangi	35	5.6	1.359	668	265	3.06	213	10	160	105
10	Mosque Ghosia Rehamania. Landi	35	7.4	5.68	2960	200	0.38	1752	7	110	90
11	Cattle Colony, Shah Latif Town	110	7.7	2.78	1406	205	0.36	680	105	120	85
12	Cattle Colony Milk Farm 1 Shah Latif Town	80	6.9	3.27	1664	387	0.46	810	40	220	167
13	Cattle Coloney Milk Farm 2 Shah Latif Town	150	7.6	2.57	1294	262	0.68	690	10	110	152
14	Al-Shafi Hospital Thatta	40	7.1	4.19	2160	178	3.24	1200	38	90	88
15	Sada Bahar Area, Thatta	25	5.9	0.779	377	112	0.43	144	8	68	44
16	Kinger Lake, Thatta	40	6.5	0.761	369	103	0.45	155	10	79	24
17	Makli Grave Yard, Thatta	60	7.2	5.02	2610	264	0.71	1576	37	240	24
18	Mazar Mai Makli, Thatta	100	6.8	23.2	13310	184	304.01	8884	667	94	90
19	Shamsi Society, Malir	80	7.4	1.701	838	134	0.43	358	48	110	24
20	Ice Factory, Industrial Area, Korangi	80	7.1	44.6	27300	558	4.41	18590	524	240	318
21	Tanree CLeather Factory, Korangi	150	7.8	10.29	5540	352	0.24	3506	290	160	192
22	Attock etroleum, Industrial Area, Landi	80	7.8	2.51	1254	216	0.22	690	26	120	96
23	Habib Chorangi, Sher Shah	60	6.8	0.799	386	70	0.33	170	20	46	24
24	Ismailia Garveyard,Layari	80	6.9	5.6	2940	324	0.58	1694	80	210	114
25	Saddar Karachi, Akbar Road	110	7.1	2.13	1058	208	0.32	474	47	160	48
26	Gulshan-e-Hadeed, Steel Town	200	7	8.46	4490	219	0.61	2867	324	147	72
27	Dhabeji city	70	7.1	2.39	1205	376	0.25	538	58	280	96
28	Gharo City	35	7.4	0.689	333	99	0.86	134	9	64	35

29	MirpurSakro City	40	6.4	1.068	522	199	0.25	187	34	115	84
30	Pak Coast Guard Check Post, Gharho	25	7.3	0.692	334	128	8.33	105	20	80	48
31	Keti-Bandar City	35	7.1	1.288	632	188	14.4	260	34	120	68
32	Thatta City		6.7	2.28	1139	330	0.76	440	87	240	90

can negatively impact infrastructure by causing scaling in pipes and equipment. This scaling can lead to increased maintenance and repair costs, along with reduced operational efficiency.

Sulfate and chloride levels were found to be significantly higher than previously reported, aligning with earlier research that noted slight increases in areas with intensive agricultural activities. Our findings, however, reveal even greater levels of sulfate and chloride contamination. This suggests that runoff from fertilizers and pesticides, alongside untreated industrial discharge, continues to adversely affect groundwater quality.

Conclusions

The hydrochemical analysis of groundwater along the Sindh coastal belt highlights significant contamination, particularly in industrial and agricultural zones. Elevated levels of TDS, hardness, and other ions pose health risks, warranting immediate remedial actions. Policy measures, such as stringent regulations on industrial effluents and improved waste management, are essential to protect the quality of groundwater resources.

Conflict of interest

The authors declare no conflict of interest.

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