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Groundwater Quality Assessment through Water Quality Index (WQI) in New Karachi Town, Karachi, Pakistan

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Abstract: The aim of present study is to evaluate the groundwater quality of New Karachi Town using water quality index (WQI) measured through physico-chemical parameters. For this purpose, a total of 25 groundwater samples were randomly collected through boring wells at a depth range of 9-61 metres from the study area. Data revealed that TDS content of groundwater is very high (mean: 4781.6 mg/L) which far exceeded the WHO limit for drinking purpose. Highly elevated concentrations of Na (mean: 1397 mg/L), K (mean: 39.72 mg/L), Ca (mean: 308.7 mg/L), Mg (mean: 1408.65 mg/L), Cl (mean: 2502.345 mg/L), HCO_3 (mean: 441 mg/L) and SO_4 (mean: 332.4376 mg/L) are reported in more than 85% wells which also exceed the WHO guideline for drinking water. Very high concentration of these major ions (Mg, K, Ca, Na, Cl, SO_4 and HCO_3) indicates the sewage mixing with groundwater in the study area. The calculated value of water quality index (WQI = 189) indicated that groundwater in New Karachi Town is not suitable for drinking and for irrigation or industrial purpose. Thus, proper treatment of the available groundwater is required before its any public use in the area.

Key words: Groundwater quality, physico-chemical parameters, water quality index, New Karachi town.

Introduction

Water is essential component of all forms of life and it is mainly obtained from two sources, i.e. surface water which includes rivers, canals, fresh water lakes, streams etc. and ground water like well water and borehole water (McMurry and Fay, 2004). More than half of the world depends on ground water for survival (UNESCO, 1992) and in present scenario, rapid increase in population results in depletion of water resources. In order to fulfill the demand, ground water acts as a major source. According to World Health Organization (WHO) about 80% of all the diseases are water-borne. Water quality is the reflection of its composition which is affected by natural and anthropogenic activities in terms of measurable quantities (Kumar, 1997). Therefore the capability to predict the behaviour of contaminants in flowing ground water is of vital importance for the reliable assessment of hazardous or risks arising from groundwater contamination problems, and the design of efficient and effective techniques to mitigate them. Karachi is the largest and densely populated city of Pakistan where water is supplied through pipelines. However, due to rapidly growing population and scarcity of municipality supplied water, demand-supply balance has been adversely affected in the city. As a result, people living in the city are now depending more upon the ground water to meet their daily needs. The over abstraction of ground water depletes water table and accelerates the contaminants transport from the land surface to aquifer (Shah and Roy, 2002), which ultimately affects the aquifers badly.

Domestic and industrial effluents contribute to the increase in concentration of different pollutants in

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ground water (Reghunath et al., 2002). Moreover, the quality of ground water is not yet properly determined in the city to ensure its potential domestic use, especially for drinking purpose. There is an urgent need to assess the Karachi groundwater quality. Present study is based on determining physico-chemical characteristics of ground water in New Karachi Town (67°3′10.674″E-67°5′12.5196″E and 24°57′55.5552″N-24°59′59.802″N). WQI is one of the most effective tools to communicate information on the quality of water to the concerned citizens and policy makers (Yisa and Jimoh, 2010). It was first proposed by Horton (1965) then in 1970 general WQI was developed by Brown et al. (1970). It is a single number that rates the water quality by aggregating several water quality parameters and usually the higher score alludes to the better quality (excellent, good) and the lower score to degraded quality (bad, poor) (Bharti, 2011). The objective of this study is to determine the quality of ground water from the area and to determine its suitability for drinking purpose using Water Quality Index.

Study Area

New Karachi Town of the central district of Karachi is located in northern part of Karachi positioned between 67°3′10.674″E-67°5′12.5196″E longitudes and 24°57′55.5552″N-24°59′59.802″N latitudes (Figure 1). New Karachi town is residential as well as an industrial part of Karachi covering an area of 20.47 sq. km with dense population of 1,038,865 (KSMP, 2007). Lyari River is located at a distance of 5.2 km in northeast of New Karachi. Geologically, the surface of this town is mostly covered with alluvium. Manchar and Gaj formations of Pliocene and Miocene ages respectively are also exposed on the surface of New Karachi Town (Figure 1). Subsurface geology of study area comprises Nari Formation of Oligocene age, which consists of sandstone with interbedded shales and subordinate limestones (Pithawalla and Martin-Kaye, 1946). Nari Formation is overlain by Gaj Formation which is 50 m thick in Karachi; predominantly soft to hard sandstone with subordinate argillaceous limestone (Shah, 2009). Manchar Formation overlies Gaj Formation which constitutes non-fossiliferous sandstones associated with marl beds (Pithawalla and Martin-Kaye, 1946). Based on the thickness of Gaj Formation, it is assumed that most of the wells (90%) of the study area occur in the aquifers of Manchar and Gaj Formations within the depth range of 16-46 m while other aquifers are in the Nari Formation (Table 1).

Materials and Methods

Sample Collection

Twenty five groundwater samples were collected from boring wells at a depth range of 9-61 metres. Ground water was electrically pumped for 2-3 minutes to get representative samples. Location of the wells

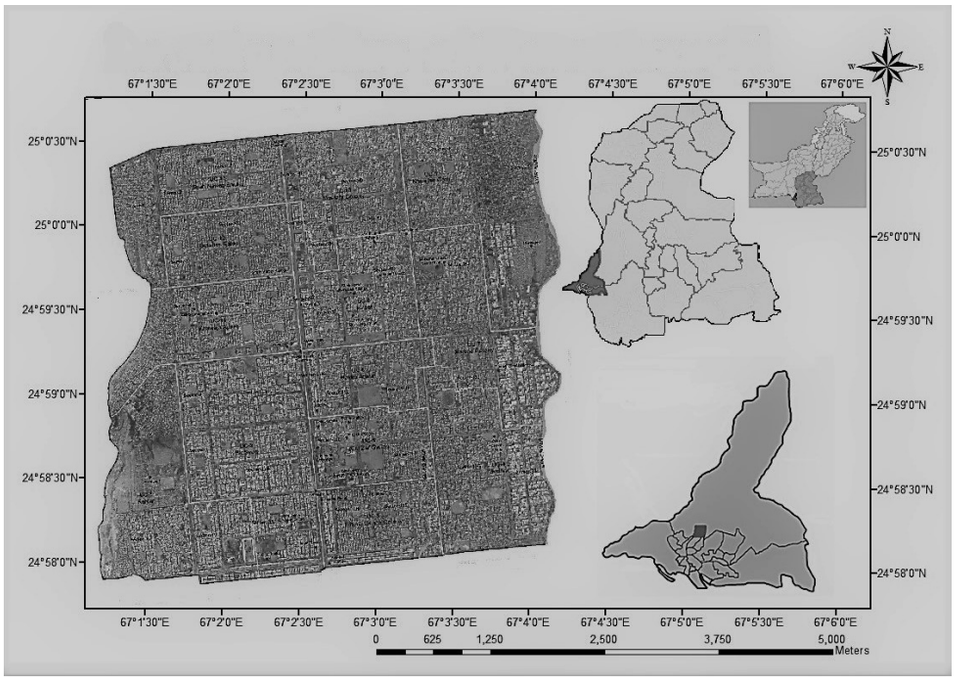

Figure 1: Location map of New Karachi Town.

Table 1: Physico-chemical parameters determined in groundwater of New Karachi Town

	Physical Properties			*Major Cations*				*Major Anions*			
S. No	*Depth metres*	*pH -*	*TDS mg/L*	*Na mg/L*	*K mg/L*	*Ca mg/L*	*Mg mg/L*	*Cl mg/L*	*NO_3 mg/L*	*SO_4 mg/L*	*HCO_3 mg/L*
1	37	7.53	3660	2100	51	90	719.533	1311.65	11.99	284.9	400
2	40	7.51	6880	2900	54	244	785.177	3243.68	2.509	366.3	575
3	-	7.01	2410	1040	42	164	915.037	1028.05	6.2	244.2	525
4	24	7.59	4130	1640	27	110	733.318	1134.4	11.54	374.44	400
5	34	7.25	3980	1880	29	210	1007.24	1932.03	14.41	252.34	400
6	18	6.68	20800	7540	77	1754	5863.44	13453.3	3.573	203.5	400
7	18	7.29	3210	1200	38	204	1007.61	1435.73	1.336	317.46	400
8	18	7.33	3620	565	41	550	1541.59	638.1	6.196	317.46	325
9	24	7.26	23900	4500	76	1680	6967.94	17246.4	11.65	512.82	400
10	-	7.21	3520	1040	41	220	1261.64	1932.03	5.812	252.34	375
11	37	7.26	16300	5340	66	700	3902.48	10280.5	6.508	358.16	225
12	30	7.18	3750	530	45	188	1173.58	903.975	11.9	382.58	600
13	10	6.77	3180	640	57	376	1647.16	1134.4	11.08	431.42	400
14	-	7.48	2170	570	40	184	713.822	762.175	4.278	341.88	450
15	9	7.07	1100	165	53	160	850.28	319.05	5.688	358.16	375
16	30	7.52	1160	308	20	30	563.178	411.22	3.666	260.48	875
17	61	7.39	1390	294	24	100	533.925	537.068	9.655	284.9	400
18	30	7.11	1750	300	26	146	911.131	728.498	25.16	293.04	500
19	55	7.42	1710	429	20	112	768.196	616.83	19.27	301.18	625
20	46	7.72	3620	550	14	90	514.533	709	18.47	382.58	650
21	37	7.41	1530	227	35	132	641.981	636.328	2.778	284.9	400
22	14	7.32	1240	252	26	90	624.533	427.173	3.666	276.76	350
23	21	7.32	2000	375	45	92	814.411	797.625	4.34	569.8	400
24	30	7.93	1060	226	18	50	386.963	373.998	2.585	301.18	225
25	-	7.48	1470	315	28	42	367.449	565.428	5.245	358.16	350
WHO limit	-	**6.5-8.5**	**500**	**200**	**12**	**75**	**150**	**250**	**10**	**250**	**300**
Mean	29.6667	7.3216	4781.6	1397	39.72	308.7	1408.65	2502.345	8.3802	332.4376	441
Max	61	7.93	23900	7540	77	1754	6967.94	17246.43	25.16	569.8	875
Min	9	6.68	1060	165	14	30	367.449	319.05	1.336	203.5	225
St. Dev	13.7562	0.2707	6112.853	1848.4	17.37	450.8	1663.61	4370.527	6.054586	82.90155	139.7319

was marked with the help of Global Positioning System (GPS) on the Google earth image (Figure 2). Groundwater samples were collected in plastic bottles of 1.5 litre capacity for physico-chemical analysis. Bottles were properly washed and rinsed thoroughly with distilled water and then with ground water at sampling site. To determine nitrate concentration, groundwater samples were collected in bottles of 100 ml capacity and one ml boric acid solution was injected through sterile syringe in each water sample to cease any further reaction.

Groundwater Analysis

All the physico-chemical tests were carried out in the laboratory of Department of Geology, University of Karachi. The pH and TDS or EC of collected

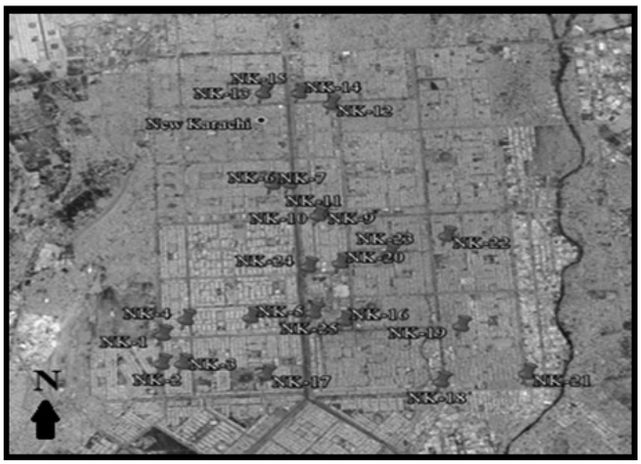

Figure 2: Sample location map of study area.

groundwater samples (n = 25) were measured with the glass electrode pH meter (Adwa AD 111) and EC meter (Adwa AD 330) respectively. Sodium and potassium concentration was determined by the flame photometer (Model No. JENWAY PFP7). Sulphate content was tested by gravimetric method, while bicarbonate and chloride was estimated by argentometric titration method. The method used for the analysis of calcium and total hardness was EDTA Titration Standard Method (1992). Magnesium was estimated as the difference between hardness and calcium with the help of a formula. Groundwater samples preserved in the boric acid were analyzed to determine the nitrate concentration by Cadmium Reduction method (HACH-8171) on Spectrophotometer.

Water Quality Index (WQI)

Weighted arithmetic index method of WQI proposed by Brown et al. (1970) was applied to evaluate the water quality status of the ground water in the New Karachi Town. Physico-chemical parameters including pH, TDS, major cations (Na, K, Ca, Mg) and anions (HCO_3, Cl, SO_4, NO_3) were used to calculate WQI of ground water in New Karachi Town. *WQI* is calculated by using following formula.

$$WQI = \sum Q_n W_n / \sum W_n$$

where Q_n is the quality rating of nth water quality parameter and W_n is the unit weight of nth water quality parameter.

The quality rating Q_n is calculated using the equation

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

where V_n is the actual amount of nth parameter present, V_i is the ideal value of the parameter, V_i = 0, except for pH (V_i = 7) and V_s is the 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 Discussions

Physicochemical Parameters

Groundwater quality of collected samples (n = 25) from various parts of New Karachi Town is found to be worst for drinking purpose. Extremely wide range of total dissolved content (TDS) is reported (mean: 4781.6 mg/L) which violate the WHO permissible limit (500 mg/L) in all the groundwater samples, where it ranges between 1060-23900 mg/L (Table 1). Similarly, all collected samples deviated from Pakistani permissible limit (1000 mg/L) of TDS for drinking purpose. The pH fluctuates between slightly acidic to slightly alkaline (6.68-7.93) which is within the WHO guideline (6.5-8.5) for drinking water.

Sodium and chloride concentration distribution is very heterogeneous where both varied in the range of 165-7540 mg/L and 319.05-17246.425 mg/L respectively. The mean concentration of both Na and Cl is found to exceed the WHO allowed values of 200 and 250 mg/L respectively. All the collected groundwater samples exceeded the permissible concentration of Na and Cl (Table 1). It indicates the same factor is responsible for increase in concentration of these two ions in the ground water of study area. Calcium content showed wide variation, where it is varied between 30-1754 mg/L. Except few samples (n = 3), all the wells showed excessive Ca concentration against WHO reference value of 75 (Table 1). Mg content is highly variable (range: 367.4485-6967.94 mg/L) with a mean of 1408.645 mg/L.

All the groundwater samples contain elevated concentration of Mg, which are also high in the Ca and K (range: 14-77 mg/L) contents along with HCO_3 (range: 225-875 mg/L) and Cl (range: 319.05-17246.43 mg/L), which indicates sewage mixing with groundwater results in increased TDS content (Cole et al., 2004). All the collected samples show more Mg concentration than Ca, which indicates the groundwater interaction with dolomitic rocks (Sarala and Ravi, 2012) and sewage mixing in ground water of study area. Bicarbonate

concentration occurred between 225-875 mg/L with a mean of 441 mg/L, where except two samples, all the collected samples (n = 25) are found to be affected by elevated bicarbonate content. Sulphate content is determined in the range of 203.5-569.8 mg/L with a mean of 332.438 mg/L. Except two, all the groundwater samples are beyond the permissible limit of WHO (250 mg/L) for drinking purpose (Table 1).

High concentration of SO_4 in ground water may be due to the discharge of industrial wastes and domestic sewage (Srivastava et al., 2012). Nitrate content is found to be variable (range: 1.336-25.16) with mean value of 8.3802. About two third of total collected samples showed NO_3 concentration <10 mg/L while rest of the samples exceeded the permissible limit, recommended by WHO (2011) for drinking water. It indicates that nitrate reducing bacteria are active in the ground water of study area, which is supported by exceptionally high bicarbonate content suggesting that organic matter decomposition is followed by nitrate reduction in the ground water of study area (Davis and De Wiest, 1966).

Water Quality Index

Weighted arithmetic index method of WQI is used to determine the quality of ground water in New Karachi Town. It is a simple method aimed to giving a single value to the water quality by translating the list of parameters and their concentrations present in a sample into a single value, which in turn provides an extensive interpretation of the quality of water and its suitability for various purposes like drinking, irrigation, industrial etc. (Abbasi, 2002). First step for calculating WQI of ground water is to estimate the quality rating of each parameter using the formula: $Q_n = 100*[(V_n - V_i)/(V_s - V_i)]$. If quality rating $Q_n = 0$ means complete absence of pollutants, while $0 < Q_n < 100$ implies that the pollutants are within the prescribed standard and when $Q_n > 100$ implies that the pollutants are above the standards (Gungoa, 2016). In collected samples of ground water Q_n of TDS, Na, K, Ca, Mg, HCO_3, SO_4 and Cl are above 100 (Table 2) which indicates that these are the main components that are deteriorating the water quality.

Second step is to calculate the unit weight (W_n) of all the physico-chemical parameters with the help of formula: $W_n = k/V_n$, which is shown in Table 2.

Calculated result of WQI (Table 2) shows that the ground water of New Karachi Town is not suitable for drinking purpose, as suggested by the Brown et al. (1972). Water quality of collected samples is unfit for drinking, as value of WQI is above 150 (WQI = 189) (Table 3) which means that proper treatment of ground water is required before using for any purpose.

Table 2: Water Quality Index of collected groundwater samples from New Karachi Town

Parameters	*pH*	*TDS*	*Na*	*K*	*Ca*	*Mg*	*Cl*	*NO_3*	*SO_4*	*HCO_3*
	-	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*
Observed value (V_n)	7.32	4781.6	1397.04	39.7	308.7	1408.6	2502.3	8.38	332.44	441
WHO limits (V_s)	8.5	500	200	12	75	150	250	10	250	300
Ideal value (V_i)	7	0	0	0	0	0	0	0	0	0
Q_n	21.44	956.32	698.52	331	411.6	939.1	1000.9	83.8	132.98	147
$W_n = k/V_n$	0.34	0.0059	0.0182	0.30	0.049	0.024	0.0145	0.364	0.015	0.012
Q_n*W_n	7.43	5.6368	12.7	100.3	19.95	22.77	14.559	30.47	1.934	1.782
Water Quality Index $=\sum q_i W_n/\sum W_n = 189$										

Table 3: WQI range, status and possible usage of the water sample (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

The quality of ground water from New Karachi Town is not suitable for drinking purpose. The main parameters deteriorating the quality of water are TDS, Mg, Ca, Na, K, SO_4, HCO_3 and Cl. High contents of TDS, Na and Cl indicate the mixing of sewage water which may infiltrate from the Liyari river, which is flowing at 5.2 km in northeast of study area. Calculated value of WQI shows that the ground water is grouped into the category of water quality, which is unfit for drinking as suggested by Brown et al. (1972) which indicates that it is unfit for drinking as well as irrigation and industrial purpose and proper treatment is required before use.

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