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Fate of Urban Groundwater in Shallow Confined Aquifers: Case Study of Baldia Town, Karachi, Pakistan

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Abstract

A study was carried out to assess the groundwater quality for drinking purpose in Baldia Town, Karachi. For this purpose, groundwater samples (n = 18) were randomly collected from various depths (> 100 feet) through boring wells after monsoon season. Data revealed that except two (BT-5, 8) which were turbid and smoky, rest of the samples were colorless, non-turbid and sweet in taste. Groundwater temperature fluctuates between 19-26 ˚C. The pH varies between slightly acidic to slightly basic (range: 6.8-7.3) where two third of total samples have pH < 7. All the samples have very high TDS content (range: 1240-16910 mg/L; mean: 6832 mg/L) which exceeded the national drinking water quality standard (1000 mg/L) set by PCRWR. Hardness values varied in the extreme range (1000-9500 mg/L; mean: 2366 mg/L). Relative abundance of major cations follows the order of Mg > Ca > Na> K while anions varied in the order of HCO_3> SO_4> NO_3> Cl. Dissolved Fe^{+3} (mean: 0.01 mg/L) varies within WHO permissible limit (0.3 mg/L) while Mn showed concentration < 0.01 mg/L. Concentration of trace elements declined in the order of Ni > Zn > Cr > Co. It is concluded that groundwater of study area not fit for drinking purpose. It is strongly influenced by semi-arid climate and water rock interaction which is manifested by geochemical signatures of limestone (Ca, Zn) and clays (Ni, Co, Cr). Due to confined aquifer system the anthropogenic contamination is not significant.

Keywords: groundwater, quality, drinking purpose, confined aquifers, urban setup, Karachi

1. Introduction

Water sustains life on the earth as it is an essential component of the environment. It is available on the earth as surface and groundwater (Sarada and Bhushanavathi, 2015). About 80% of all the diseases in human beings are caused by water (WHO). Hence, analysis of the water quality is very important to preserve and prefect the natural eco-system (Dohare et al, 2014). The pollution of groundwater is of major concern because of its increasing use for human needs and industrial activity. The rapid growth of population, urbanization, industrialization and increasing use of chemicals have resulted in water pollution which is increasing day by day (Qin et al., 2014; Knudsen and Slooff, 1992).

Groundwater is believed to be comparatively much clean and free from pollution than surface water. But prolonged discharge of industrial effluents, domestic sewage, sea water intrusion and solid waste dump causes the groundwater to become polluted and creates health problems (Sarada and Bhushanavathi, 2015). The physico-chemical contaminants that adversely affect the quality of groundwater is likely to arise from a variety of sources, including land application of agricultural chemicals and organic wastes, infiltration of irrigation water, septic tanks, and infiltration of effluent from sewage treatment plants, pits, lagoons and ponds used for storage (Pathak and Limaye, 2012). Water quality standards are needed to determine whether groundwater of a certain quality is suitable for its intended use.

Chemical weathering is the dominant weathering process in warm, humid environments. It happens when water, oxygen, and other reactants chemically degrade the mineral components of bedrock and turn them into water-soluble ions which can subsequently be transported by water (Johnson et al., 2017). Rate of chemical weathering is accelerated by increasing temperature. Rocks experience faster rates of chemical weathering in hot and wet climate as compared to cold and dry climates. Similarly, chemical weathering only occurs on rock surfaces because water and reactants cannot penetrate solid rock. The role of sedimentary rocks is imperative while serving as catchment area for rainwater. Especially for shallow aquifers where rocks are more reactive toward chemical attack. These statements are more relevant in coastal cities like Karachi.

It becomes more appealing if the limestone exposures intercept the pristine meteoric water first. Based on this hypothesis, Baldia town was taken as a precedence to delineate the repercussion of water-rock interaction where limestone is forming catchment area. Moreover, industrial effluent and municipal sewage were also assumed to be the sources of contamination in urban set up of Karachi city. If this would be the case, then health and life of the public is questioned as a result of drinking such groundwater in study area. Hence, there is a dire need of assessing the fate of groundwater in urban set up where water is tapped from shallow confined aquifers. Despite such grave concern, no study has been carried out so far in study area to screen the groundwater for its quality determination. Therefore, present study is aimed at assessing the groundwater quality of Baldia Town using hydrogeochemical approach. Other objective is to find out the sources of contaminants in study area.

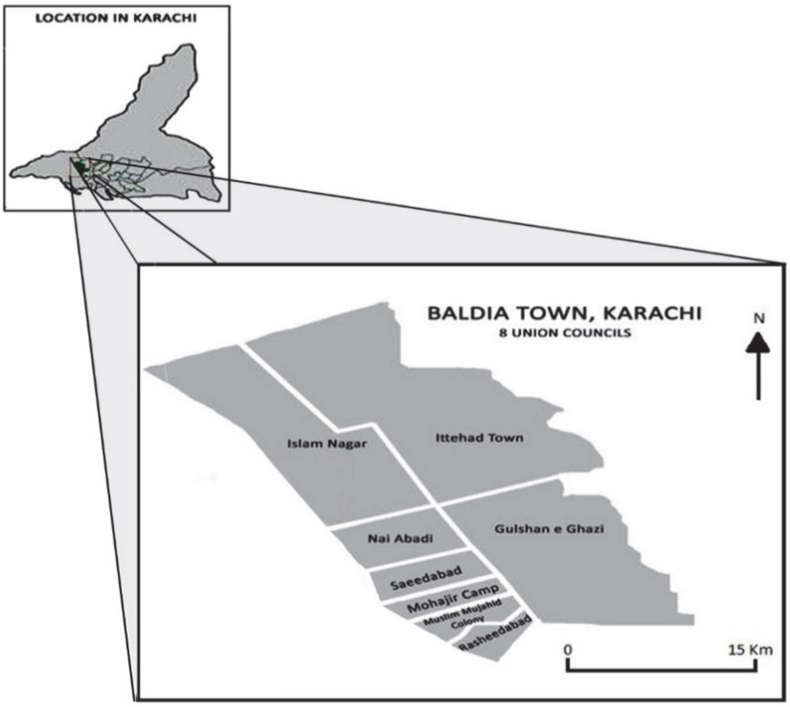

Figure 1. Showing the location map of study area

2. Materials and Method

2.1 Study Area

Baldia Town is located in the western part of Karachi, Sindh, Pakistan with latitude and longitude of 24°55′28″N - 66°58′25″E and 24.92444°N - 66.97361°E respectively (Figure 1). The area is bordered by SITE Town and Orangi Town to the east and by Kemari Town to the north and west, with most of the western boundary formed by part of RCD Highway. Many industries are located nearby study area as an integral part of SITE area on the east. The condition of sewerage system in Baldia Town is poor which is deteriorating day by day. Sewerage pipelines are broken sporadically in study area. When the drains are chocked, the sewerage water comes up and spills out in the study area. As a result, roads are severely damaged (cracked or pitted) or completely eroded away. Due to poor maintenance of the roads, most of the paved parts are washed out and unpaved surfaces are triggering infiltration of water in large amount. It becomes more pronounced during rainy season Geologically, Baldia town rest on the limestone member of Gaj Formation which belongs to Miocene age (Figure 2). This limestone is interlayered by thin shale units which is served as ductile material during westward collision of Indian plate after Eocene time.

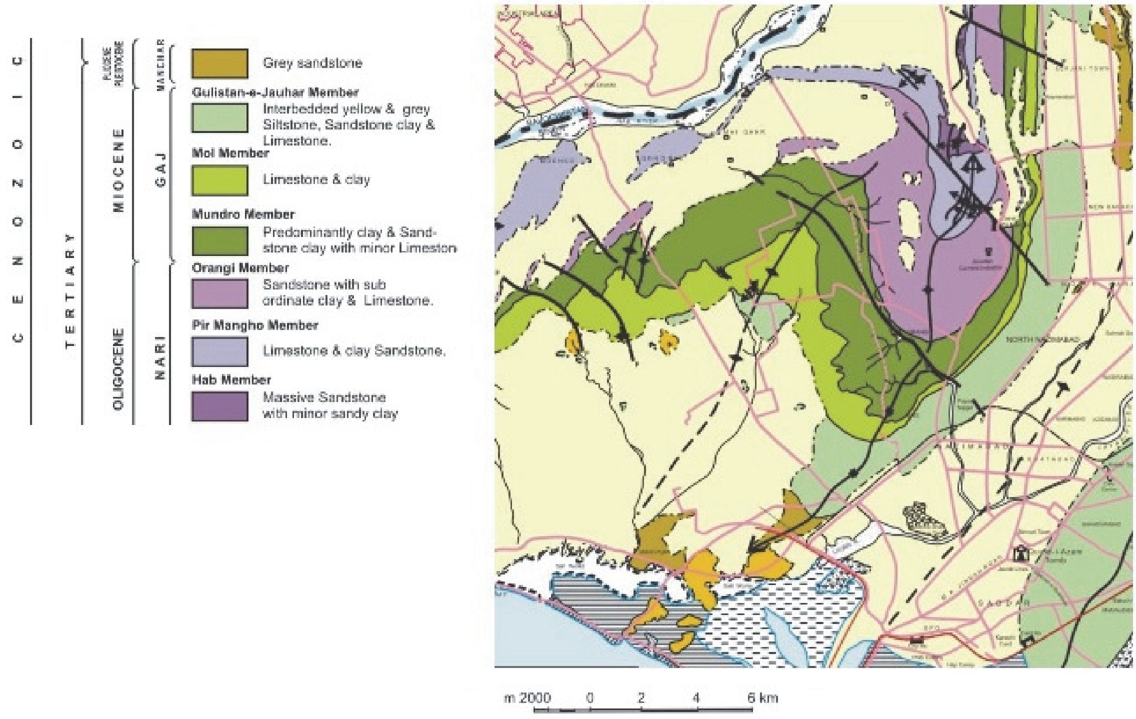

Figure 2. Geological map of study area

This resulted in the formation of several asymmetrical folds followed by multiple normal faults in Karachi and its suburbs. Baldia town is located between western limb of Manghopir anticline and Lalji syncline (Figure 3). The periphery of Lalji syncline is serving as catchment area for Baldia town basin where many streams are formed between dip and escarp slopes of limestone ridges. Groundwater table occurs at a depth of > 100 feet due to steep inclination of the rocks forming the confined aquifer system. The general groundwater flow direction is northwest to southeast.

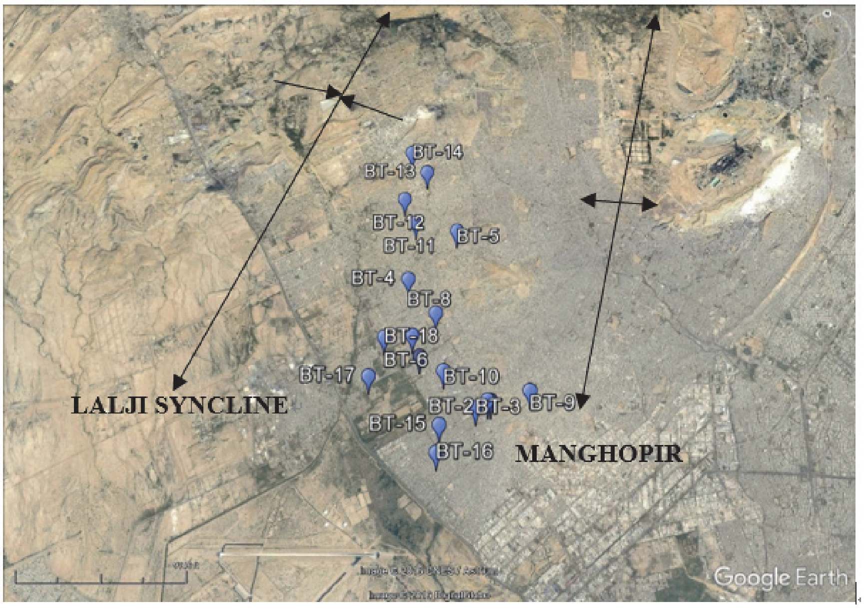

Figure 3. Sample location map of study area

2.2 Sample Collection

Groundwater samples (n = 18) were taken from various depths (> 100 feet) through electrically pumped boring wells. The samples were collected after running pump for approximately 3 minutes to remove the standing water in the well pipe. Plastic bottles of 1.5-liter capacity were used for sample collection. Bottles of 200 ml volume were also used for the analysis of nitrate in which boric acid was mixed in a small quantity. Before sampling, bottles were properly washed and rinsed with distilled water and well water respectively. Aesthetic characteristics of samples include color, taste, odor, temperature and turbidity. Locations of the wells were marked with the help of Global Positioning System (GPS).

2.3 Sample Analysis

The pH of collected groundwater samples was measured with pH meter (JENCO 6230N). Turbidity was visually observed where translucent samples were regarded turbid and transparent samples were declared clear/non-turbid. TDS and EC were measured with the help of EC meter (Eutech Cyber Scan CON 11). Sodium and potassium concentrations were determined by using flame photometer (Model No. Jenway PFP7). Ca was determined by EDTA titration method while Mg concentration was derived from standard formula using difference between Ca concentration and hardness content. Sulphate content was determined by gravimetric method and chloride was measured by standard titration method using silver nitrate. Similarly, HCO_3 was also estimated by standard titration method. On the other hand, minor (Fe and Mn) and trace (Ni, Cr, Co, Zn) elements were analyzed by atomic absorption spectrometer at flame mode (Model No. Analyst 400 Perkin Elmer).

3. Results and Discussion

3.1 Physical Characteristics

The taste, odor and color of samples were normal except for sample BT-5 and BT-8 which appear smoky while taken from wells (Table 1). Water quality is good in terms of aesthetic characters as large number of water samples were found safe. Color, cloudiness, particulate matter and visible organisms may create concerns about the quality of a drinking-water (WHO, 2006). Taste and odor in drinking-water may be indicators of some forms of pollution i.e. the presence of potentially harmful substances (WHO, 2017). All the samples were clear except BT-5 and BT-8 (Table 1). Turbidity in water is caused by suspended matter, such as clay, silt, finely divided organic and inorganic matter, soluble colored organic compounds, plankton and other microscopic organisms (Fink, 2005). Generally, it is transported to the aquifer depth through water infiltration from surface (Bitton, 1992). The pH of collected samples ranges between 6.78 - 7.32 with a mean of 6.96. Thus, the pH of groundwater is within the WHO permissible range of 6.5 - 8.5. The pH less than 6.5 or greater than 9.2 is not suitable for drinking-water purposes (WHO, 1985). About two third of total collected samples are slightly acidic (pH< 7). The lowering of pH is attributed to organic acids, by dissolution of sulphide minerals or decaying of vegetation (Davis and DeWiest, 1966). Organic acid generation can dissolve silicates more effectively as compared to inorganic acids leading to lower the pH groundwater (Zhang et al., 2009).

Although pH has no direct impact on human health but values above WHO guidelines (6.5-8.5) can impair the potability of drinking water (WHO, 1993). Toxicity of cyanides and sulphides increase with decrease in pH and ammonia becomes more toxic with pH increase (Williams, 2003).

The TDS content ranges between 1240 – 16910 mg/l, with a mean of 6832.78 mg/l. Mean TDS content of groundwater in all collected samples is about 7 and 14 times higher than the Pakistan Environmental Protection Agency (1000 mg/L) and WHO (500 mg/L) guideline values for drinking water. TDS content is mainly comprising of inorganic salts of bicarbonates, chlorides and sulphates. Larger variation in TDS is mainly attributed to anthropogenic activities and to geochemical processes (Jeevanandam et al, 2007) prevailing in the region.

Table 1. Physical characteristics of groundwater samples collected from Baldia Town

Sample No.	Well type	Depth ft	Color	Turbidity	Odor	Taste	Temp °C	pH	TDS mg/l	EC µs/cm	Hardness mg/l
BT-1	Boring well	110	Colorless	Clear	Odorless	Sweet	24	6.98	6400	12.76	2400
BT-2	Boring well	90	Colorless	Clear	Odorless	Sweet	22	6.81	1500	2.99	1400
BT-3	Boring	130	Colorless	Clear	Odorless	Sweet	23	7.11	2440	4.88	1300

	well										
BT-4	Boring well	150	Colorless	Clear	Odorless	Sweet	22	6.80	1950	3.9	9500
BT-5	Boring well	170	Smoky	Turbid	Odorless	Sweet	26	6.95	15200	30.40	4000
BT-6	Boring well	150	Colorless	Clear	Odorless	Sweet	23	7.04	1240	2.48	1300
BT-7	Boring well	180	Colorless	Clear	Odorless	Sweet	22	7.04	2880	5.86	1500
BT-8	Boring well	150	Smoky	Turbid	Odorless	Sweet	21	6.84	4080	5.52	1500
BT-9	Boring well	150	Colorless	Clear	Odorless	Sweet	19	6.82	7900	15.8	1700
BT-10	Boring well	120	Colorless	Clear	Odorless	Sweet	24	6.91	8720	17.42	1800
BT-11	Boring well	110	Colorless	Clear	Odorless	Sweet	25	6.93	12500	25.30	2500
BT-12	Boring well	160	Colorless	Clear	Odorless	Sweet	22	7.07	16910	8.49	2500
BT-13	Boring well	170	Colorless	Clear	Odorless	Sweet	25	6.78	11200	22.60	3400
BT-14	Boring well	120	Colorless	Clear	Odorless	Sweet	23	6.92	10700	21.40	1200
BT-15	Boring well	110	Colorless	Clear	Odorless	Sweet	22	6.95	1640	3.28	2000
BT-16	Boring well	100	Colorless	Clear	Odorless	Sweet	25	7.32	11400	22.8	1400
BT-17	Boring well	120	Colorless	Clear	Odorless	Sweet	19	7.05	2570	7.75	1000
BT-18	Boring well	150	Colorless	Clear	Odorless	Sweet	21	6.88	3760	7.5	2200

3.2 Water Solute Chemistry

3.2.1 Major Cations

Highly variable concentration (range: 80.98 – 798.5 mg/l; mean: 350.2 mg/l) of sodium occurs. Except five samples (BT-1, BT-13, BT-15, BT-17 and BT-18) the concentration of sodium is above WHO (1993) permissible limit (200 mg/l) set for drinking water (Table 2). Calcium concentration varied from 130 to 2160 mg/l, with a mean of 513.67 mg/l (Table 2). The prescribed limit of calcium in drinking water is 200 mg/l (WHO, 1976). About two third of the total wells (n = 18) showed objectionable concentration of Ca for drinking purpose. Likewise, a wide range of magnesium concentration (range: 230 – 2298 mg/l; mean: 543.39 mg/l) is reported in the groundwater of Baldia Town. Prescribed limit of magnesium in drinking water is 100 mg/l (WHO, 1976) where all the samples exceeded the permissible guideline (Table 2). About 83% of the samples showed more than 5 times the recommended value by WHO. Potassium concentration ranges from 5.01 to 41.14 mg/l, with a mean of 22.72 mg/l. Maximum allowed limit of potassium in drinking water by WHO is 12 mg/l (WHO, 2009). Unfortunately, about two third of total samples showed concentration above 12 mg/l (Table 2). This elevated concentration of K causes hyperkalaemia which causes nausea, muscle fatigue, paralysis, weakness and abnormal heart rhythms.

3.2.2 Major Anions

Highly variable concentration of bicarbonate (range: 300 to 650 mg/l; mean: 452.78 mg/l) occurs in the groundwater of study area where it is the dominant anion. The concentration of bicarbonate should not exceed 300 mg/l in drinking water (WHO, 2004). Except two, all the wells are reported to contain elevated content of bicarbonate (Table 2). About one third of total samples show HCO_3 content above 500 mg/L. Sulphate is second major anion and its concentration also shows large deviation (range: 22 – 1174 mg/l; mean: 138.39 mg/l). Health based guideline for sulphate in drinking water is 500 mg/ liter (WHO, 2006). About two third of total collected samples have SO_4 content < 100 mg/. Only one sample (BT-13) has shown anomalous concentration (1174 mg/l) of sulphate where the calcium content is also very high (1360 mg/l). It suggests the gypsum dissolution from gypsiferrous shales. Similarly, very low concentration of chloride (range: 2–29 mg/l; mean: 12.8 mg/l). According of Pakistan standards, permissible limit of chloride in drinking-water is less than 250 mg/l. Nitrate has also shown variable ranges (5.05- 76.22 mg/l) with mean of 28 mg/l. Guideline value of nitrate in drinking-water is 10 mg/l (WHO, 1993). About two third of total wells showed excessive nitrate content (NO_3 > 10 mg/l).

3.2.3 Minor and Trace Elements

Iron and manganese varied in the range of 0.0026 - 0.0231 and 0.0009 - 0.0081 mg/l with a mean of < 0.01 and 0.001 mg/l respectively. Both are within the corresponding guideline values of 0.3 and 0.1 mg/l respectively set by WHO (2011) for drinking water.

Nickel concentration varied from 404 to 605 µg/l. The concentration of nickel in drinking-water is normally acceptable up to 20 µg/l (WHO, 2005). Interestingly all the collected samples violate the prescribed limit of WHO. Conversely, chromium and cobalt concentrations varied in the range of 3.1 – 23.6 and 0.4 - 3.7µg/l respectively. Both these elements are found within the corresponding limit (50 µg/l) of WHO (2006) set for drinking water. Likewise, zinc content varied in the range of 23–311 µg/l in terms of zinc concentration, the groundwater qualifies both the WHO and Pakistani guideline values of 3000 and 5000 µg/l respectively (WHO, 1993).

Table 2. Chemical characteristics of groundwater samples collected from Baldia Town

Sample No.	**Major Cations**				**Major Anions**				**Minor Ions**		**Trace Elements**			
	mg/l				**mg/l**				**mg/l**		**µg/l**			
Well Code	Na	Ca	Mg	K	HCO_3	SO_4	Cl	NO_3	Fe	Mn	Ni	Cr	Co	Zn
BT-1	166.20	440	556	24.115	300	97	13.5	15.82	0.0035	0.0021	48	0.52	0.36	3.1
BT-2	299.85	160	330	28.42	400	42	17	5.54	0.0039	0.0016	39.7	0.66	0.18	3.4
BT-3	523.78	216	302	22.39	400	25	4.5	18.98	0.0075	0.0046	42.6	0.69	0.37	2.3
BT-4	428.05	160	2298	24.77	650	23	3	19.96	0.0080	0.0047	40.4	2.36	0.14	3.3
BT-5	204.28	2160	840	41.14	550	60	29	5.174	0.0126	0.0036	60.5	0.84	0.31	9.2
BT-6	226.62	130	308	8.30	500	51	14.6	24.07	0.0111	0.0031	42.2	0.77	0.25	3.8
BT-7	746.79	200	352	11.29	550	45	5	23.84	0.0026	0.0009	43.1	0.31	0.21	3.4
BT-8	617.74	530	332	12.01	500	43	4	31.94	0.0033	0.0081	43.9	0.66	0.04	2.8
BT-9	222.70	640	374	32.93	450	158	16	1.96	0.0100	0.0030	48.2	0.74	0.16	9.0
BT-10	230.85	520	405	32.04	300	142	16.5	6.534	0.0231	0.0035	50.6	0.98	0.28	19.6
BT-11	366.95	940	550	31.84	350	169	15	13.96	0.0097	0.0034	49.4	1.07	0.25	8.5
BT-12	228.97	420	581	20.18	500	122	16.5	49.4	0.0080	0.0071	49.9	1.26	0.17	31.1
BT-13	91.47	1360	743	30.51	450	1174	23	61.02	0.0078	0.0030	53.8	1.21	0.26	28.6
BT-14	735.88	480	262	35.64	400	138	21	43.38	0.0108	0.0041	53.0	1.25	0.29	5.6
BT-15	80.98	200	473	10.97	500	22	2	49.44	0.0074	0.0041	44.2	0.4	0.2	4.5
BT-16	798.50	240	325	30.48	500	130	21	5.047	0.0086	0.0070	54.1	0.85	0.05	8.4
BT-17	187.84	210	230	5.013	400	22	4	76.22	0.0071	0.0036	42.9	0.64	0.08	1.7
BT-18	146.14	240	520	6.99	450	28	4	51.56	0.0056	0.0078	44.1	1.1	0.13	2.4

3.2.4 Interrelationships Among Physicochemical Parameters

Weak correlation of pH is observed with all parameters except sodium where a moderately positive correlation (r = 0.4) is observed (Table 3). Weak correlation of pH with other parameters is consistent with the fact that very low range (6.8-7.3) of pH variation occurs in the groundwater of study area. TDS content revealed the strong correlation with Ca (r = 0.66), K (r = 0.65) and Cl (r = 0.75). This relationship suggests that these ions are responsible for the high TDS content in the groundwater of study area. Moreover, strong affinity of TDS with trace elements like Ni (r = 0.88) and Zn (r = 0.7) suggest that pH of groundwater has been disturbed by some chemical imbalances leading to lower the pH of groundwater. It is evident by the acidic pH in one third of total collected samples (Table 2). It is well established that acidification trigger the process of heavy metal desorption (Kjøller et. al, 2004). Hardness showed the strong correlations with Mg (r = 1.0), HCO_3 (r = 0.55) and Cr (0.8). Similarly, Mg showed strong correlation with HCO_3 (r = 0.56) and Cr (0.43). This relationship clearly explains the role of ion exchange to alter the hardness type from Ca to Mg. Generally, the Mg in groundwater comes from dolomitic limestone dissolution or from clays enriched with brucite $Mg(OH)_2$. When the pH is lowered by chemical imbalance this brucite layer releases its OH into the groundwater to maintain the pH. As a result, magnesium is co-released with its conjugate acid into water. In study area clay units are dominantly composed of illite, montmorillonite and chlorite intermittently exposed with Talawa limestone of Gaj Formation (Figure 2). These clays are the main source of magnesium which is also evident by the strong correlation of hardness with Cr (Table 3). Upon subtle changes in pH of groundwater, the clays tend to release sorbed load of trace elements to maintain the pH equilibrium. Strong correlation of Ca with K ($r^2 = 0.61$), Cl ($r^2 = 0.67$) SO_4 ($r^2 = 0.45$) and Ni ($r^2 = 0.78$) suggest that the groundwater has been infiltrated by passing through gypsiferrous clay layers. Iron showed the moderate positive correlation with Ni ($r^2 = 0.45$) while Zn and Ni showed strong positive correlation with each other ($r^2 = 0.52$) indicating that a large part of Zn is released from the clays instead of limestone. Conversely, Mn expressed strong negative relationship with Co ($r^2 = - 0.53$). This reverse relationship is manifested due to the fact that Mn is more mobile in aerobic environment while Co is more mobile in anaerobic aquatic environments than in aerobic freshwater environments (Mahara & Kudo, 1981).

Table 3. Statistical Descriptive of Groundwaters Parameters

S. No.	**Parameters**	**Min**	**Max**	**Mean**	**S.D**
1	Well Depth	90	180	135	25.87
2	Temperature	19	26	22.67	1.91
3	pH	6.78	7.32	6.96	0.13
4	TDS	1240	16910	6832	4967
5	Hardness	1000	9500	2366.67	1892.38
6	Ca	130	2160	513.67	503.59
7	Mg	230	2298	543.3	455
8	Na	80.98	798.5	350.2	228.60
9	K	5.01	41.14	22.72	10.80
10	HCO_3	300	650	452.7	87.36
11	Cl-	2	29	12.76	7.96
12	SO_4	22	1174	138.3	256.2
13	NO_3	5.05	76.22	27.99	21.55
14	Fe	0.0026	0.012	0.008	0.001
15	Mn	0.001	0.008	0.004	0.004
16	Ni	39.7	60.5	47.26	5.48
17	Co	0.05	0.37	0.21	0.10
18	Cr	0.40	2.36	0.91	0.45
19	Zn	1.70	31.1	8.37	8.65

3.2.5 Role of Confined Aquifer System

Despite the occurrence of dense population and industrial hub around Baldia Town, the role of anthropogenic input to contaminate the groundwater is insignificant. The occurrence of trace elements in very low concentration (< 0.0001 mg/l) is an indicator of confined aquifer system. It is consistent with the fact that most trace elements are characterized by low mobility under alkaline and reducing conditions. Moreover, the concentrations of trace elements in confined aquifers are much smaller than the maximum permissible values for drinking water (Levins and Gosk, 2008). However, very high TDS content coupled with objectionable hardness is attributed to the semi-arid climate and low recharging characteristics of shallow aquifers in study area. A part of major solutes may be incorporated through salt leaching from roads and wetting of the engineered structures during rainy seasons.

Table 4. Correlation Matric among physicochemical parameters of collected groundwater samples from Baldia Town, Karachi

	Well depth	Temp	pH	TDS	Hardness	Na	Ca	Mg	K	HCO_3	SO_4	Cl	NO_3	Fe	Mn	Ni	Cr	Co	Zn
Well depth	1.00																		
Temp	-0.06	1.00																	
pH	-0.21	0.21	1.00																
TDS	0.16	0.52*	0.15	1.00															
Hardness	0.29	0.15	-0.38	0.03	1.00														
Na	-0.06	0.09	0.40	0.00	-0.12	1.00													
Ca	0.38	0.55*	-0.25	0.66**	0.19	-0.25	1.00												
Mg	0.27	0.12	-0.36	-0.02	1.00**	-0.10	0.12	1.00											
K	-0.13	0.58*	-0.16	0.65**	0.22	0.11	0.61**	0.18	1.00										
HCO_3	0.57*	-0.11	0.01	-0.10	0.55*	0.21	0.03	0.56*	-0.18	1.00									
SO4	0.28	0.35	-0.30	0.35	0.09	-0.24	0.45	0.06	0.30	-0.09	1.00								
Cl	0.01	0.63**	0.03	0.75**	-0.07	-0.05	0.67**	-0.12	0.78**	-0.16	0.43	1.00							
NO_3	0.19	-0.35	-0.06	-0.09	-0.09	-0.27	-0.13	-0.08	-0.56*	0.05	0.29	-0.33	1.00						
Fe	-0.06	0.33	0.00	0.37	0.04	-0.18	0.29	0.02	0.45	-0.25	0.06	0.43	-0.26	1.00					
Mn	0.06	-0.12	0.20	0.20	0.05	0.17	-0.11	0.05	-0.21	0.25	-0.15	-0.19	0.25	-0.05	1.00				
Ni	0.14	0.64**	0.15	0.88**	-0.02	0.00	0.78**	-0.07	0.70**	-0.10	0.40	0.82**	-0.14	0.45	0.08	1.00			
Cr	0.18	0.11	-0.32	0.22	0.80**	0.01	0.06	0.81**	0.29	0.35	0.18	0.07	0.06	0.24	0.29	0.06	1.00		
Co	0.02	0.53*	-0.05	0.16	-0.02	-0.20	0.33	-0.04	0.40	-0.41	0.16	0.32	-0.23	0.29	-0.53*	0.26	-0.10	1.00	
Zn	0.30	0.31	-0.06	0.70**	0.08	-0.29	0.39	0.05	0.35	-0.06	0.65**	0.51*	0.17	0.39	0.11	0.52*	0.27	0.11	1.00

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

4. Conclusion

Present study revealed that groundwater of Baldia Town is not suitable for drinking purpose due to its very high hardness (mean hardness: 2366 mg/L) and salt content (Mean TDS: 6832 mg/l), which may cause different diseases and disabilities upon long term use. High salt content is due to the excessive amount of major salts of Mg, Ca, Na and K while the high hardness is attributed to elevated concentration of bicarbonate and sulphate ions. The hardness of water is temporary (bicarbonate) which can be removed by boiling. Trace element geochemistry revealed that limestone dissolution (Ca, Zn) and ion exchange from shales (Ni, Co, Cr) are main natural processes to alter the chemistry of groundwater in study area. Despite the occurrence of industrial hub, anthropogenic contamination is not obvious which is due to the confined nature of shallow (depth < 200 ft) aquifers in study area. Further studies are required to understand the factors retarding the groundwater contamination from industrial and municipal waste in the proximity of study area.

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References

Bitton, G., & Harvey, R.W. (1992). Transport of pathogens through soil and aquifers. In Mitchell, R. (Ed.), *Env. Microbiology* (pp. 103-124), New York, Wiley-liss.

Davis., & De Viest. (1966). *Hydrogeology*, 453. New York, John Wiley & Sons,

Dohare, D., Deshpande, S., & Kotiya, A. (2014). Analysis of Ground Water Quality Parameters: A Review. *Research Journal of Engineering Sciences, 3*(5), 26-31.

Fink, J. C. (2005). *Establishing a relationship between sediment concentrations and turbidity.* In the effects of urbanization on Baird creek, Green Bay, WI (Thesis).

Jeevanandam, M., Kannan, R., Srinivasalu, S., & Rammohan, V. (2007). Hydrogeochemistry and Groundwater Quality Assessment of Lower part of the Ponnaiyar River Basin, Cuddalore District, South India. *Environ. Monit. Assess*, *132*(1-3), 263-274. https://doi.org/10.1007/s10661-006-9532-y

Johnson, C., Matthew, D., Affolter., Inkenbrandt, P., & Mosher, C. (2017). An Introduction to Geology. Salt Lake Community College, USA.

Kjøller, C., Postma, D., & Larsen, F. (2004). Groundwater Acidification and the Mobilization of Trace Metals in a Sandy Aquifer. *Environmental Science and Technology*, *38*(10), 2829-35. https://doi.org/10.1021/es030133v

Knudsen, A. B., & Slooff, R. (1992). Vector-borne disease problems in rapid urbanization: new approaches to vector control. *Bull World Health Organ, 70*(1), 1-6.

Levins, I., & Gosk, E. (2008). Trace elements in groundwater as indicators of anthropogenic impact. *Environmental Geology, 55*(2), 285–290. https://doi.org/10.1007/s00254-007-1003-4

Mahara, Y., & Kudo, A. (1981). Interaction and mobility of cobalt-60 between water and sediments in marine environments possible effects by acid rain. *Water Research*, *15*(4), 413–419. https://doi.org/10.1016/0043-1354(81)90051-8

Pathak, H., & Limaye, S. N. (2012). Assessment of Physico-Chemical Quality of Groundwater in rural area nearby Sagar city, MP, India. *Advances in Applied Science Research*, *3*(1), 555-562.

Qin, H., Su, Q., Khu, S., & Tang. N. (2014). Water Quality Changes during Rapid Urbanization in the Shenzhen River Catchment: An Integrated View of Socio-Economic and Infrastructure Development. *Sustainability, 6*, 7433-7451. https://doi.org/10.3390/su6107433

Sarada, P., & Bhushanavathi, P. (2015). Analysis of Groundwater Samples of Gnanapuram Area of Visakhapatnam City in Andhra Pradesh, India for Sodium, Potassium and Chloride: The Potability Concern. *Global Journal for Research Analysis, 4*(10).

Williams, M. D., Coffey, B. M., & Krasner, S. W. (2003). Evaluation of pH and ammonia for controlling bromate during cryptosporidium disinfection. *J. Am. Water Works Assco., 95*(10), 82-93. https://doi.org/10.1002/j.1551-8833.2003.tb10476.x

World Health Organization. (1976). Document A29/INFDOCI/1, Geneva, Switzerland: Union of the physically impaired against segregation. Fundamental principles of disability, London.

World Health Organization. (1985). Guidelines for the study of dietary intakes of chemical contaminants, Geneva.

World Health Organization. (1993). Guidelines for drinking-water quality, Geneva.

World Health Organization. (2004). Guidelines for drinking-water quality, Geneva.

World Health Organization. (2005). Nickel in drinking-water. Background document for development of WHO Guidelines for drinking-water quality. Geneva, World Health Organization (WHO/SDE/WSH/05.08/55).

World Health Organization. (2006). *Guidelines for drinking-water quality* (3rd ed).

World Health Organization. (2009). Potassium in drinking water. Background document for preparation of WHO guidelines for drinking-water quality, Geneva, World Health Organization WHO/HSE/WSH/09.01/7).

World Health Organization. (2011). *Guidelines for drinking-water quality* (4th ed).

World Health Organization. (2017). Guidelines for drinking water quality (4th ed).

Zhang, Y., Zeng, J., & Yu, B., (2009). Experimental study on interaction between simulated sandstone and acidic fluid. *Pet. Sci., 6*, 816. https://doi.org/10.1007/s12182-009-0002-3

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