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Groundwater Quality Determination for Drinking Purpose by Using Water Quality Index Technique: A Case Study of Gadap Town, Karachi, Pakistan

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Abstract

Present study is aimed at assessment of groundwater quality of Gadap Town for drinking purpose using water quality index (WQI) technique. Gadap is located in the outskirt of Karachi city and mainly influenced by the agriculture activities. Groundwater samples (n = 22) were collected mainly from boring wells and a few through tube wells from variable depths (100-600 feet). The analytical results of water reveal occurrence of very high TDS (range: 466-3810; mean: 1402) and hardness contents (range: 250-2800 mg/L). On the other hand, pH varies (range: 6.9-8.1; mean: 7.5) within WHO guidelines (6.5-8.5) with a few samples showing turbidity. About one third of total collected samples (n = 8) were analyzed for qualitative determination of microbial contamination which are found positive, except one sample, indicating the sewage mixing. Major chemistry of groundwater is also found disturbed in terms of high content of Na (mean: 219 mg/L), K (mean: 15 mg/L), Ca (mean: 144 mg/L) and Mg (mean: mg/L 137). Similarly, anions varied in the order of Cl > HCO3 > SO4 > NO3. Although some parameters show the bad quality of water but Water quality index (WQI) value (16.18) indicates that the groundwater quality is suitable for drinking purpose. It is inferred from the present study that water quality is partly polluted due to anthropogenic activities mainly by sewage infiltration.

Keywords: Groundwater, Geochemistry, Drinking quality, WQI, Gadap Town, Karachi.

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Contents

Contribution of this paper to the literature
This paper will augment the worth of WQI technique being used for explaining the water quality objectively. It will also add the information about groundwater behavior occurring in the suburbs of the mega city.

1. Introduction

Groundwater is one of the imperative natural resource to drive the life cycle. It is widely used for various purposes including industry, drinking, washing and irrigation. It can only be used if available in sufficient quantity with acceptable quality [1]. Hydrological cycle naturally works as a big pump which continuously transfers the water from oceans to land; mainly underground [2]. Modern agricultural practices, urbanization and industrialization have created the menace of water pollution [3]. These anthropogenic activities not only alter the physicochemical characters of water bodies but also contaminate the environment. Once the groundwater gets polluted it is difficult and costly to be cleaned up. Hence, to identify the potential toxicants and mechanism of release from their sources is important to prevent these water resources. Agricultural practices are common in areas where the fertile soil and water is available in copious amount. However, due to nutrient deficiency in agricultural soils, plenty of fertilizer or manure is used to get required crop yield. On the other hand, eutrophication, a result of high nutrient loads (mainly nitrogen and phosphorus), is considered to be the prevailing water quality problem for surface water [4]. Other pollutants originating in agricultural activities include sediments, oxygen-demanding substances and pesticides. Similarly, salinization is also reported as the most widespread groundwater quality problem and as having the greatest environmental and economic impacts [5]. This in turn leads to release various toxic elements into the water which ultimately contaminate the groundwater resources. This groundwater is also used by the dwellers of the agriculture-based community as main source of cooking, washing and drinking. As a result, the health and life of such community gets threatened. It is therefore important to monitor and regulate the groundwater of such areas to prevent from any catastrophe.

About 60% of urban population in Pakistan is using groundwater for drinking and domestic purpose without regulating the water as per World Health Organization (WHO) standards [1]. Karachi is the largest city of Pakistan which is blessed with several ephemeral streams and channels culminating at two main rivers namely Lyari and Malir which ultimately discharge to Arabian Sea. The land around these natural water courses is being used for agricultural activities since long. Some agricultural sites are still pristine however others are rapidly transforming into the urban centers. Gadap Town is the agricultural periphery of Karachi city which is the hub of vegetable supply to this mega city and adjoining areas. Some reports on the base line data have shown the occurrence of high nitrate in the groundwater of Gadap (e.g. Chughtai, et al. [6]). As a result, the health of people living in Gadap town is questioned. However, no detailed work has been carried out so far to address the groundwater quality and possible sources of contamination in this part of Karachi city. Therefore, present study is aimed at assessing the groundwater quality of Gadap town using a new approach i.e. water quality index (WQI). Other objective is to statistically trace out the factors responsible for influencing the chemistry of groundwater in study area.

2. Materials and Methods

2.1. Study Area

Gadap town is subdivision of Malir district which situated in the northwestern part of Karachi city Figure 1. This town is also forming the provincial border between Sindh and Balochistan, while to the north and east are Jamshoro district and the Kirthar Mountains. Gadap town has 8 union councils with over 400 rural villages accommodating the population of about 289,564 (1998). Gadap basin is influenced by the ephemeral channels occurring in the outskirt of Karachi city and mainly influenced by the agriculture activities. Over the last decade the Gadap is transformed into semi-area urban.

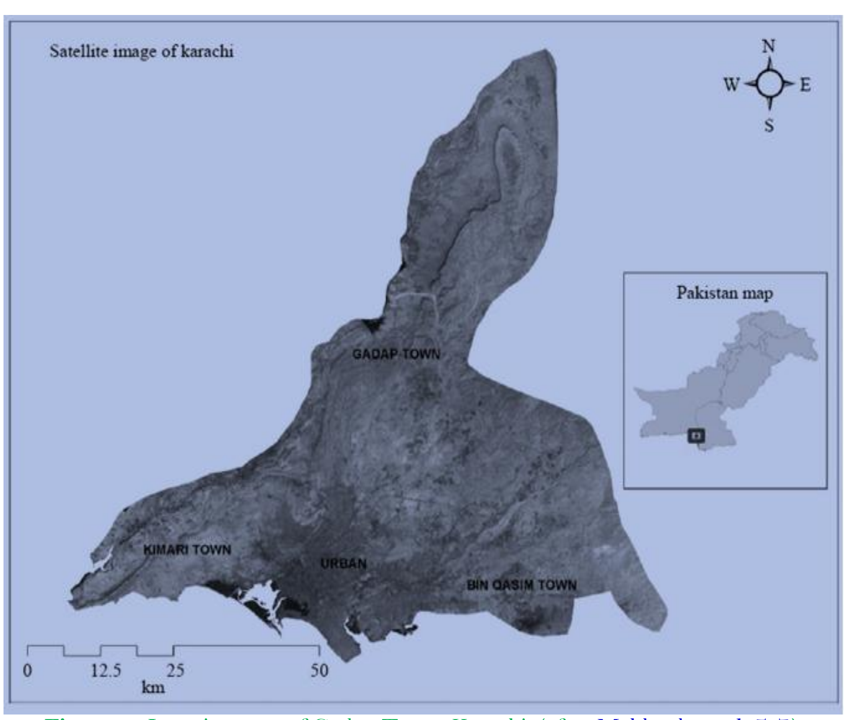

Figure-1. Location map of Gadap Town, Karachi, (after Mahboob, et al. [7]).
Source: This map has been taken from Mahboob, et al. [7] paper which is cited in the figure caption.

2.2. Sample Collection

Twenty-two groundwater samples were collected from boring wells at a depth range of 100-600ft. Groundwater was electrically pumped for 2-3 minutes to get true samples. Location of the wells was marked with the help of Global Positioning System (GPS) on the Google earth image and transformed on the map prepared by using GIS Technique Figure 2. Groundwater samples were collected in plastic bottles of 1.5-liter capacity for physico-chemical analysis. Bottles were properly washed and rinsed thoroughly with distilled water and then with groundwater 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.

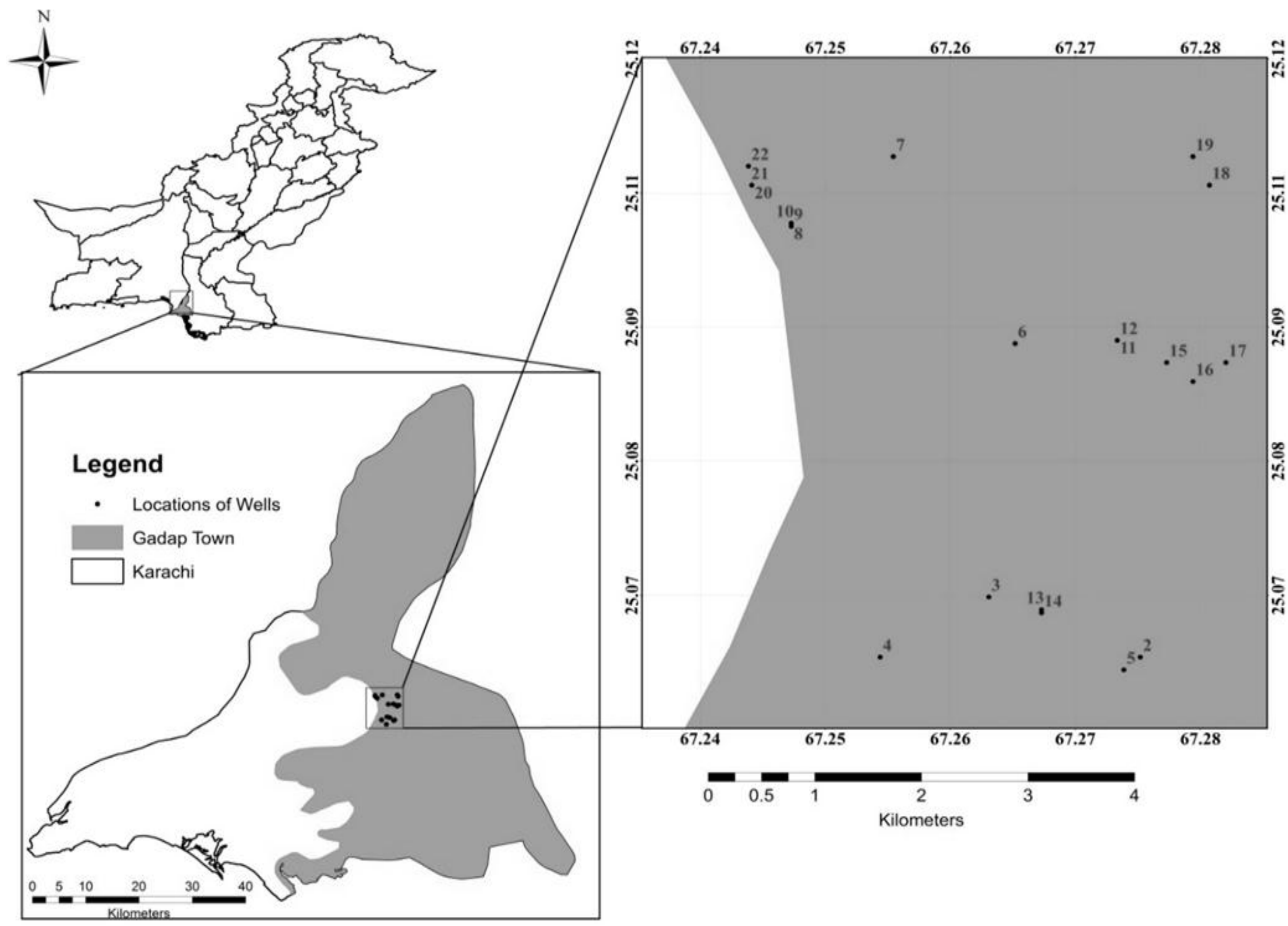

Figure-2. Sample location map of study area.

2.3. Groundwater Analysis

All the physico-chemical tests were carried out in the laboratory of Geology Department, University of Karachi. The pH and TDS/EC of collected groundwater samples (n=22) were measured with the glass electrode pH meter (ADWA AD 111) and EC meter (ADWA AD 330) respectively. Concentration of sodium and potassium was determined by using flame photometer (Model No. JENWAY PFP7). Sulphate content was tested by gravimetric method, while bicarbonate and chloride were estimated by Argenometric 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 formula. Groundwater samples preserved in the boric acid were analyzed to determine the nitrate concentration by Cadmium Reduction method (HACH-8171) on Spectrophotometer.

2.4. Water Quality Index (WQI)

Groundwater quality index of Gadap town was determined by using weighted arithmetic index method as proposed by Brown, et al. [8] to evaluate the water quality status of study area. Physicochemical 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 groundwater in Gadap town. WQI is calculated by using following formula.

$$WQI=\sum QnWn / \sum Wn$$

Where,
Qn is the quality rating of nth water quality parameter.
Wn is the unit weight of nth water quality parameter.
The quality rating Qn is calculated using the equation .

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

Where,
Vn is the actual amount of nth parameter present.
Vi is the ideal value of the parameter, Vi = 0, except for pH (Vi = 7).
Vs is the standard permissible value for the nth water quality parameter.
Unit weight (Wn) is calculated using the formula.

$$W_n = k / V_n,$$

Where, k is the constant of proportionality and it is calculated using the equation

$$K= 1 / \sum Vs= 1, 2, \ldots, n$$

3. Results and Discussion

3.1. Physical Parameters

The characteristics of collected groundwater samples (n = 22) have been summarized in Table 1. Although a few samples are slightly saline and some show yellow color but others are safe in terms of color, taste and odor Table 1. The groundwater pH is slightly alkaline (mean: 7.5) with subtle variation in range (6.9-8.1) which is within the permissible range of WHO (6.5-8.5) for drinking. The groundwater temperature is low (mean: 28 °C) which fluctuates between 25 to 32°C suggesting that it's meteoric origin which has been hosted in the aquifers through surface water infiltration [9-17]. Only 5 samples (10, 13, 18, 21 and 22) are found turbid Table 1 which are also sewage impacted as indicated by occurrence of pathogenic bacteria Table 1.

Turbidity in water is function of suspended load including organic particles, bacterio-plankton units, colloids, air bubbles and other non-uniformities in the water samples [18, 19]. In study area, people use to drain sewage into open pits or channels because they live in semi urban set up where lined sanitation is not yet available. As a result, organic matter and solutes are likely to infiltrate through sediments up to aquifers depths, causing high turbidity [20, 21]. Sewage contamination is reported even at the depth of 500 feet in groundwater of study area.

Generally, the sewage contamination occurs at very shallow depth but the presence of sewage at such depths seems to be the function of sediments having good transmissivity and infiltration which is characteristic of alluvial sediments comprising silty-clay to silty-sand. It is consistent with the fact that subsurface rocks in the study area are dominated by silty sand belonging to Nari Formation. These fine clastics have least tendency to hold/adsorb the organic matter on their surface as compared to clays therefore the occurrence of such organic material is plausible in the study area. Total dissolved solids (TDS) and total hardness (TH) of collected samples are found to be highly variable (466-3810 mg/L and 250 to 2800 mg/L respectively) in the groundwater of Gadap town. TDS content occur three times higher than the permissible limit of WHO (500 mg/L) for drinking water in most of the groundwater samples of study area Table 1. This wide variation in TDS content may attribute to geochemical process and anthropogenic activities [22] in the study area. As discussed earlier, the Gadap basin is an agricultural land where organic matter in the surface soil is ubiquitous. This organic matter is prime driver of generating the organic acids which is significantly leaching the ions from soil and sediments resulting in increased specific conductance or salinity of water [23]. On the other hand, semi-arid climate has also concentrated the salts in the groundwater due to intense evaporation [24, 25]. Likewise, sewage infiltration to the aquifer depth is also augmenting the salt contribution in the groundwater of Gadap basin.

3.2. Chemical Parameters

Sodium (Na) and potassium (K) are found to be highly variable in the study area ranging between 52.43-620 mg/L and 3.73-105 mg/L respectively. Na with a mean of 219.9 mg/L is found to be the dominant cation among the solutes but only in few samples exceed the permissible limit of WHO (200 mg/L) set for drinking water Table 2. Likewise, distribution pattern of calcium (Ca) is highly variable (range: 12 - 520 mg/L) in the collected samples Table 3. Similarly, the mean concentration of Mg (137.83 mg/L) in the groundwater of Gadap town is double the WHO permissible limit (50 mg/L) which spans between 12.5 to 388 mg/L Table 3. This suggests the role of multiple sources for contributing this element into the aquifer of study area.

On the other hand, K content is marginally high (mean: 15.9 mg/L) in some of the samples (n=6) violating the desired limit (12 mg/L) of WHO Table 2. Chloride (Cl) and Bicarbonate (HCO_3) are dominant anions followed by sulphate (SO_4) and nitrate (NO_3). Chloride shows elevated concentration (Mean: 597.31 mg/L) in almost all of the collected groundwater samples which is almost double the permissible limit of WHO (250 mg/L) for dirking water. However, SO_4 concentration is found to be within the permissible limit set for drinking water by WHO (250 mg/L) in all of the samples except 5 Table 2.

3.3. Ionic Interrelationship

Statistical analysis of the collected groundwater samples shows the strong positive correlation of hardness with all physical and chemical parameters except HCO_3, NO_3 and F and the same pattern is expressed by TDS Table 4. Strong positive correlation of TDS with Mg (0.6) and SO_4 (0.8) indicates the influence of Clay minerals through water rock interaction. Elevated concentration of salts (Na, K, Mg, Cl, SO_4) coupled with bacterial occurrence also suggests mixing of sewage with groundwater [26]. On the other hand, very high hardness (mean = 776.7 mg/L) of these collected samples indicate dissolution of limestone and Mg release from clays.

3.4. Hydrofacies Analysis

Hydrofacies reflect the effect of chemical processes occurring between minerals within the lithological framework and the groundwater [27]. For this purpose, the Piper diagram is used to show the relative concentration of the major cations and anions [27, 28]. The results of groundwater analysis indicate that dominant hydrofacies occurring in the aquifers of Gadap town is Mg-Cl (50%).

Table-1. Physical parameter of collected samples from GADAP town.

S. No	Locality	Depth (ft.)	Color	Taste	Odor	Turbidity	pH	TDS mg/L	EC µs/cm	Temp. ˚C	Hardness mg/L	Mico. (-ve/+ve)
1	Chanesar Goth	360	Color less	Normal	Odorless	#NT	7.3	1170	150.4	28	500	+ve
2	Khameso Goth	350	Color less	Normal	Odorless	NT	7.8	533	682.9	26.7	250	+ve
3	SorafaqirSorab Goth	300	Color less	Normal	Odorless	NT	7.4	920	1176	31.6	270	+ve
4	BadamBagh	500	Color less	Normal	Odorless	NT	7.6	1240	1562	27.1	780	+ve
5	Gabol Stop	400	Color less	Saline	Odorless	NT	7.6	1050	1382	28.5	560	-ve
6	Manzor Baloch Hotel	600	Color less	Saline	Odorless	NT	7.8	836	1073	25.1	450	TNP
7	Lucky Farm House	350	Color less	Normal	Odorless	NT	8	1370	1709	28.9	700	TNP
8	Bhitai Farm House	330	Yellow	Saline	Odorless	NT	7.1	2110	2707	27.9	1300	TNP
9	Bhitai Farm House	100	Color less	Normal	Odorless	NT	7.3	690	880.6	27.5	480	TNP
10	Bhitai Farm House	320	Color less	Saline	Odorless	Turbid	7.2	1630	2093	27.9	1030	TNP
11	Haji KhudaBaksh F.H.	220	Color less	Normal	Odorless	NT	7.4	466	595	26.4	350	TNP
12	Haji KhudaBaksh F. H.	400	Color less	Normal	Odorless	NT	7.6	532	681	30.2	500	TNP
13	Dattari Farm House	500	Color less	Normal	Odorless	Turbid	7.6	970	1240	28.3	480	TNP
14	Sarim Farm House	340	Color less	Saline	Odorless	NT	7.5	740	947.8	28.1	450	TNP
15	Radho Goth	400	Color less	Normal	Odorless	NT	7.2	3390	4780	29.4	2800	TNP
16	RadhoJokhio Goth	220	Color less	Saline	Odorless	NT	7.3	3810	5280	28.4	2350	TNP
17	Goth Rado	200	Color less	Normal	Odorless	NT	7.3	771	1083	30.1	700	TNP
18	M.Ishaq Baloch Bohlari	150	Yellow	Normal	Odorless	Turbid	7	2870	4040	30	2250	TNP
19	M.Ishaq Baloch Bohlari	120	Color less	Saline	Odorless	NT	7.3	950	1484	30.1	890	TNP
20	Gajan Village	250	Color less	Normal	Odorless	NT	8.1	790	1090	28	*TNP	+ve
21	Radho Goth	170	Yellow	Saline	Odorless	Turbid	7.6	3210	4429	29	TNP	+ve
22	Haji Arzi Village	200	Color less	Saline	Odorless	Turbid	8	800	1104	28	TNP	+ve

Note: #NT = Non turbid.
*TNP = Test not performed.

Table-2. Chemical characteristics of collected groundwater samples.

S. No.	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	Cl mg/L	HCO3 mg/L	SO4 mg/L	NO3 mg/L	Fe mg/L
1	40	97.2	319.9	6.89	514	1000	106	1.17	0.05
2	120	12.15	106.8	7.1	163.12	350	42	0.95	0.04
3	12	41.31	182.4	7.69	297.86	400	54	0.76	BDL
4	84	138.51	182.4	7.69	670.19	250	84	0.81	0.02
5	56	102.06	201.1	7.14	370.56	240	112	0.82	BDL
6	80	60.75	163.1	8.67	372.33	250	82	0.91	0.11
7	72	126.36	244.7	8.19	659.56	340	152	1.64	BDL
8	168	213.84	276.6	10.32	1219.82	340	260	1.45	0.34
9	60	80.19	108.7	5.61	241.12	300	77	2.71	BDL
10	80	201.7	197.9	9.91	886.5	310	162	0.70	0.58
11	20	72.9	52.43	3.73	156.02	230	25	1.59	0.03
12	36	99.63	70.5	4.45	187.93	260	67	1.03	BDL
13	24	102.06	193.6	7.38	429.06	320	90	0.89	0.43
14	40	85.05	158.1	5.53	219.85	380	86	0.64	BDL
15	480	388	386	20	1524.78	340	178.86	0.04	0.024
16	360	352.35	620	25	1489.32	260	341.46	0.03	0.022
17	172	65.61	120	11	141.84	300	80.13	0.03	0.01
18	520	230.85	362	19	1276.84	305	211.38	0.02	0.08
19	180	106.92	130	11	177.3	330	65.04	0.02	0.07
20	84	72	165	28	369	850	143	0.01	BDL
21	378	312	340	105	1504	490	490	0.02	BDL
22	116	71	241	32	270	750	132	0.01	BDL

Note: *BDL=Below Deduction Level.

Table-3. The statistical descriptive of the collected samples in the groundwater of the Gadap town.

Parameters	Min.	Max.	Mean	SD
Depth (ft)	100	600	308.2	130.4
pH	6.95	8.1	7.47	0.31
TDS (mg/L)	466	3810	1402	1008
EC (µm/L)	150.4	5280	1826	1466
Temp (°C)	31.6	31.6	28.42	1.46
Ca (mg/L)	520	520	144.63	150.48
Mg (mg/L)	388	388	137.83	102.25
Na (mg/L)	52.43	620	219.19	128.08
K (mg/L)	3.73	105	15.96	21.39
Cl (mg/L)	141.84	1524.78	597.31	488.45
HCO3 (mg/L)	230	1000	390.6	206.1
SO4 (mg/L)	25	490	138.22	108.51
NO3 (mg/L)	0.67	2.71	1.15	0.55

Table-4. Correlation matrix of the collected samples in the study area.

Parameters	pH	Hardness	TDS	Ca	Mg	Na	K	Cl	HCO3	SO4	NO3	Fe
pH	1											
Hardness	-0.57	1										
TDS	-0.42	0.95	1									
Ca	-0.40	0.93	0.86	1								
Mg	-0.45	0.95	0.96	0.81	1							
Na	-0.28	0.80	0.89	0.69	0.80	1						
K	0.16	0.92	0.53	0.50	0.48	0.39	1					
Cl	-0.40	0.91	0.96	0.80	0.94	0.84	0.52	1				
HCO3	0.34	-0.12	-0.09	-0.10	-0.14	0.13	0.25	-0.07	1			
SO4	-0.14	0.79	0.83	0.66	0.78	0.74	0.81	0.84	0.08	1		
NO3	-0.03	-0.53	-0.41	-0.10	-0.36	-0.40	-0.45	-0.31	-0.19	-0.35	1	
Fe	-0.15	-0.53	-0.04	-0.30	0.04	-0.10	-0.20	0.11	-0.08	0.16	0.27	1

Na-Cl (22.7%), with lesser abundance (9.10% each) of Ca-HCO_3, Ca-Cl and Na-HCO_3 Figure 3. The occurrence of Mg-Cl facies in the groundwater of study area is due to their high solubility in natural water. The dominance of these two ions clearly indicates the influence of ion exchange and clay mineral alteration or dissolution of dolomite [29-31]. Since the study area is an agricultural land where large amount of clay is present in the soil, the dominance of Mg-Cl is legitimate. On the other hand, subsurface rocks are dominated by silty clay with subordinate limestone. These rocks are also assumed to release their sorbed and structural Mg content into the aquifer system within circum-neutral pH conditions. Generally, bicarbonate species dominates in the meteoric groundwater but the occurrence of excessive chloride ion, the bicarbonate is replaced with latter one.

This chloride may originate from various sources including halite and related minerals in evaporate deposits, concentration by evaporation and solution of dry fallout from atmosphere in arid regions. The excessive amount of this ion in the groundwater is due to its conservative nature which makes it free from ion exchange, adsorption and biological activities. On the other hand, anions of strong acids (SO_4 + Cl) dominate over weak acids (HCO_3 + CO_3) which indicate anthropogenic influence in the groundwater system [32]. It is evident by the fact that intense agricultural activity is common in Gadap town since long and the unlined sanitation is also adding up the ions in the groundwater system of study area.

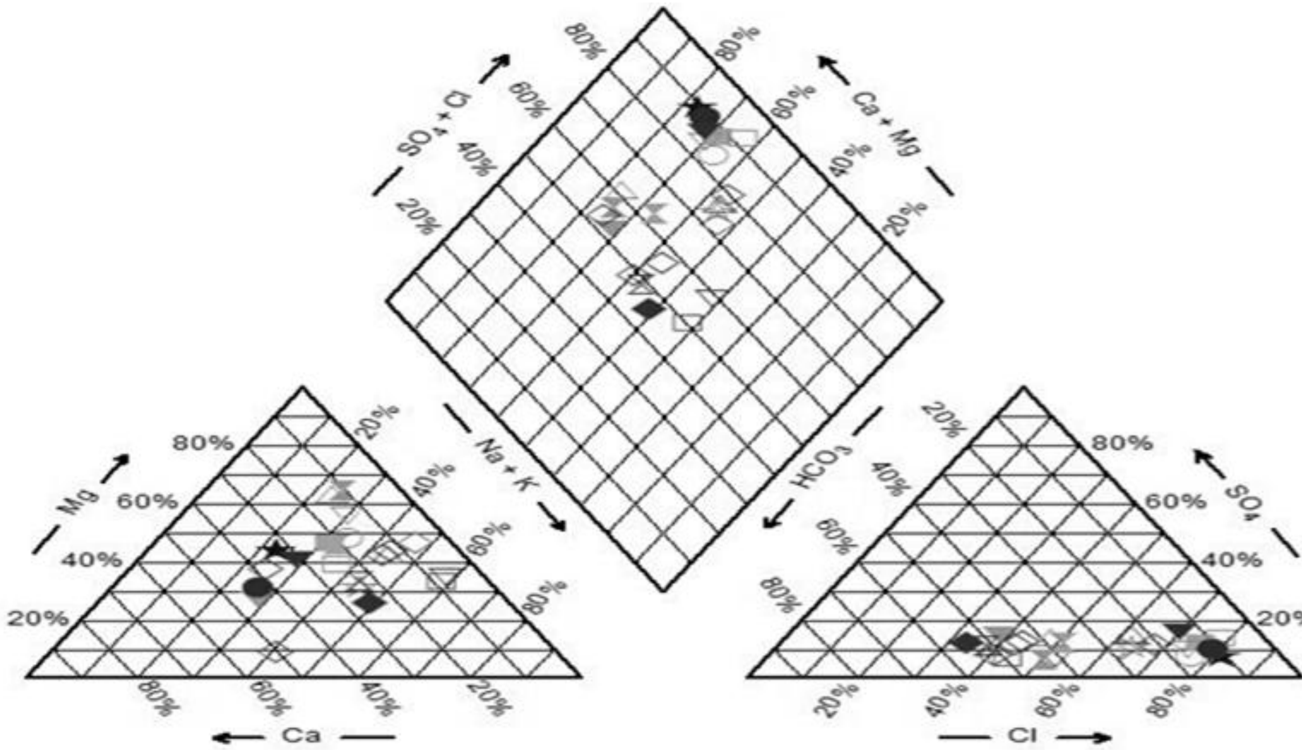

Figure-3. Piper diagram of groundwater samples from GADAP town.

3.5. WQI for Drinking Water in GADAP

The WQI considers eleven weighted parameters including pH, TDS, Hardness, Na, K, Ca, Mg, HCO_3, Cl, SO_4 and NO_3 to characterize water quality which has been summarized in Table 6. Weighted arithmetic index method of WQI has been used to assess the quality of groundwater in Gadap town. It is a simple method that aims at giving a single value to water quality by translating the list of parameters and their relative concentrations present in a sample into a single value. This single value in turn provides an extensive interpretation of the quality of water and its suitability for various purposes like drinking, irrigation, industrial etc. [33].

First step for calculating WQI of groundwater is to estimate the quality rating of each parameter using the formula: $Qn=100*[(Vn-Vi) / (Vs-Vi)]$. If quality rating Qn = 0 means complete absence of pollutants, while Qn ranging between 0 - 100 indicates that the pollutants are within the prescribed standard and in case of Qn >100 implies that, the pollutants are above the standards [34].

Table-5. Water quality index (WQI) of all collected water samples.

Parameters	Observed value (Vn)	WHO Limits (Vs)	Ideal value (Vi)	Vn-Vi	Vs-Vi	Qn	Wn=k/Vn	Qn*Wn
pH	7.5	8.5	7	0.5	1.5	33.33	0.38	12.88
TDS	1402.1	500	0	1402.1	500	280.42	0.00	0.58
Hardness	927.5	500	0	927.5	500	185.5	0.00	0.58
Na	219.1	200	0	219.1	200	109.55	0.01	1.45
K	15.9	12	0	15.9	12	132.5	0.18	24.16
Ca	144.6	75	0	144.6	75	192.8	0.02	3.86
Mg	137.8	150	0	137.8	150	91.86	0.02	1.93
Cl	597.3	250	0	597.3	250	238.92	0.00	1.16
HCO3	390.6	300	0	390.6	300	130.2	0.00	0.96
SO4	138.2	250	0	138.2	250	55.28	0.02	1.16
NO3	0.7	10	0	0.7	10	7.0	4.14	29
WQI = 16.18								

In collected samples, Qn of TDS (280.42), hardness (185.5), Ca (192.8), Na (109.55), K (132.5), HCO3 (130.2) and Cl (238.92) are above 100 which indicates that these are the main components responsible for deteriorating the water quality Table 5. Moreover, chloride and bicarbonate of Ca, Na and K are mainly responsible for elevated hardness and very high TDS content in the groundwater of study area. However, the overall result determined by operation on concerned quality parameters the WQI value of 16.18 which according to Brown, et al. [8] is still of pristine in nature Table 6.

Table-6. WQI range, status and possible usage of the water sample (Brown et al. 1972).

WQI	Water quality status (WQS)	Possible usage
0–25	Excellent	Drinking, irrigation and industrial
26–50	Good	Drinking, irrigation and industrial
51–75	Poor	Irrigation and industrial
76–100	Very poor	Irrigation
Above 100	Unsuitable for drinking and fish culture	Proper treatment required before use

Source: Brown, et al. [8].

4. Conclusion

Present study revealed that generally the groundwater quality of Gadap town is good for drinking purpose as indicated by water quality index of study area (16.18). However, some parameters are exceeding the permissible limit of WHO in a few wells. Water chemistry is being altered due to the interaction with clays in subsurface environment and anthropogenic activities (agriculture and sewage mixing). More focused study is needed to clearly understand the sources and mechanism responsible for elevating the concentrations of solutes in the groundwater of Gadap Town.

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