HYDROCHEMICAL ASSESSMENT OF THE GROUNDWATER QUALITY OF SYLHET CITY

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ABSTRACT

Most of the residents of Sylhet city depend on the groundwater supply provided by the Sylhet City Corporation (SCC). Thus, the present study points up on the groundwater hydrochemistry of this area to assess the quality for the health and daily uses of the residents of the city. Groundwater samples were collected from 20 pumps of Sylhet city during March 2019 and were analyzed for physico-chemical parameters such as Electrical conductivity (EC), Total dissolved solids (TDS), pH, Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Sodium (Na^{+}), Potassium (K^{+}), Chloride (Cl^{-}), Nitrate (NO_3^{-}), Sulphate (SO_4^{2-}), Carbonate (CO_3^{2-}) and Bi-Carbonate (HCO_3^{-}). Hydrochemical assessment has been done based on different well-known diagrams. It also describes the main features that affecting the groundwater chemistry. It has been found that Mg-Na-Ca-Cl-HCO_3 is the hydrochemical facies that dominates in the groundwater of SCC area. Almost all the samples fall in the rock area and chemical weathering of the rock forming minerals is the main processes that contribute the ions to the water. Wilcox's diagram and US Salinity Diagram were used to evaluating water quality for irrigation and they show that most samples of groundwater were good for irrigation. A further detailed study is needed based on reliable statistical methods as well as on the basis of all possible parameters and pumps under SCC.

Keywords: *Groundwater, Hydrochemistry, Hydrochemical diagrams, SAR, USSL.*

1. INTRODUCTION

Groundwater chemical composition is directly connected to groundwater quality. According to Hounslow (1995), water quality is defined by the composition of physical, chemical and biological characteristics of a water sample. The chemical composition of groundwater is the combined result of water composition that enters the groundwater reservoir and the reactions with the minerals present in the rocks (Iliopoulos, Stamatis, & Stournaras, 2011; Zhu & Anderson, 2002). Most studies as Adams et al.(2001) and Alberto et al. (2001) showed that the groundwater chemistry is mainly a function of the interaction between water and mineralogical composition of the aquifer. Hydrochemical processes occur within this system are dissolution, precipitation, and ion exchange. These events take place among the flow of groundwater and also depend on the duration of residence that controls the evolution of the chemical composition of groundwater. Chenini & Khemiri (2009) noted that the chemical composition of groundwater is controlled by several factors, including composition of precipitation, mineralogy of the watershed and aquifers, climate and topography. These factors should be combined to specify different water types that vary spatially and temporally. Graphical techniques that can help in understanding the hydrochemical process includes bar chart, pie chart, stiff diagram, schoeller diagram, piper diagram and scattered plots etc. Hydrochemical studies involve in an in-depth evaluation of the chemical composition of groundwater and therefore offer a better understanding of possible changes in quality. Such studies also promote sustainable development and effective management of groundwater.

Most of the residents of Sylhet city depend on the water supply provided by the SCC. Thus, the quality of water distributed by SCC is vital for the health of the residents of the city (Md. Munna, Islam, Hoque, Bhattacharya, & Nath, 2015). The water resources in the SCC are mostly based on groundwater, which is generally over-pumped. Despite the fact that there is a major concern regarding the quality of water in this region, research on hydrochemical and water quality studies is very low here. As a result, the hydro chemical processes (evolution), origins, mixing and quality of the water resource in SCC area are not well known. Moreover, the sources of concentration elements and sensibility of available water to pollution are not clear. This leads to great uncertainty in understanding of the major hydrochemical processes, which is one of the main elements that controls the evolution of water chemistry. Such study is indispensable for the planning and management of the water resources of the area.

Therefore, a detailed study of the groundwater quality in SCC is very essential. In addition, to the best of researchers' knowledge, no attempt has ever been made to identify the groundwater quality in the area of SCC by hydrochemical assessment.

2. METHODOLOGY

2.1 Site Description

Sylhet City Corporation area is 27.36 sq km, located in between 24°51´ and 24°55´ north latitudes and in between 91°50´ and 91°54´ east longitudes. It is bounded by Sylhet Sadar upazila on the north, Dakshin Surma upazila on the south, Sylhet Sadar upazila on the east, Dakshin Surma and Sylhet Sadar upazilas on the west. It is consisting of 27 Wards and 210 Mahallas with population about 2,70,606. Therefore, SCC represents one of the most densely populated areas and it is a challenge to SCC to fulfil the water demand of population in this area (Figure 1).

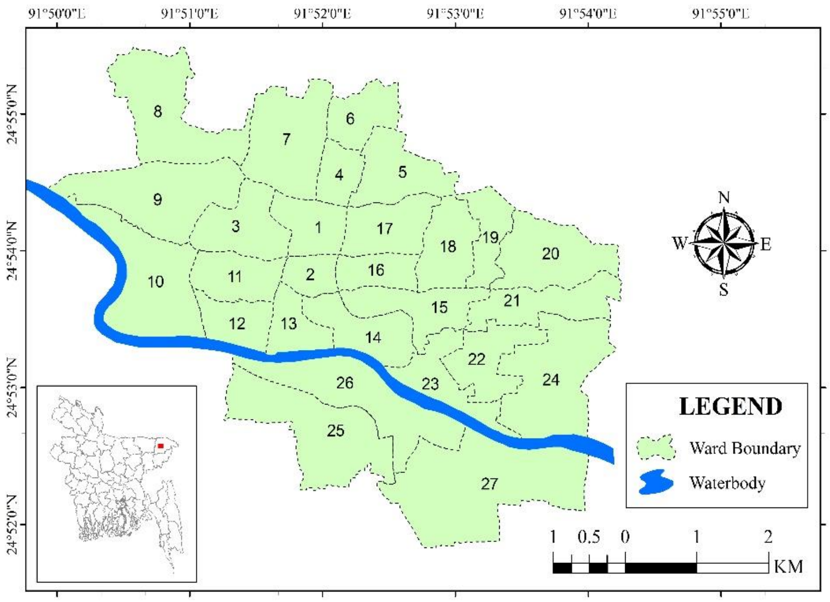


Figure 1: Administrative wards of Sylhet City Corporation

2.2 Pump Locations

At present groundwater is considered as the most important source of water supply in Bangladesh. In particular, the population density of Sylhet district is 990/km^2, which indicates a tremendous pressure on groundwater as it is the major freshwater source (Zafor et al., 2017). In the study area around 43 pumps are current operating. As described in Figure 2, 20 pumps were considered to determine the groundwater quality. These pumps were selected in such a way that the findings from this study would be generalized for the major area of the city. It should be noted that there is no pump in the south part of the city, consisting of the southern part from the Surma river.

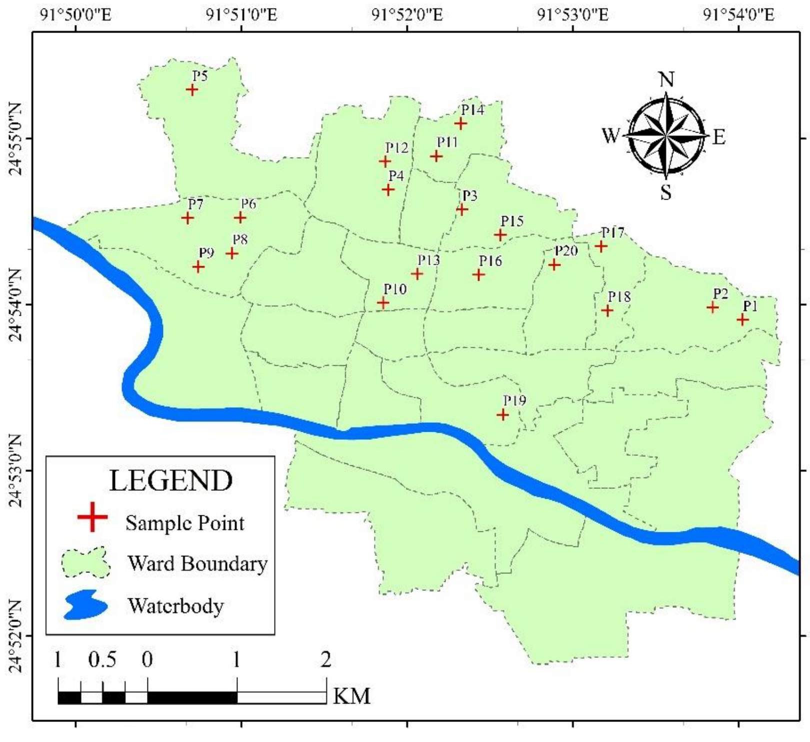


Figure 2: The Sampling pumps of Sylhet City Corporation

2.3 Data Collection and Processing

Water quality data were collected from the selected pumps during the pre-monsoon season in March 2019. The collected data are for the following parameters: Electrical conductivity (EC), Total dissolved solids (TDS), pH, Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Sodium (Na^{+}), Potassium (K^{+}), Chloride (Cl^{-}), Nitrate (NO_3^{-}), Sulphate (SO_4^{2-}), Carbonate (CO_3^{2-}) and Bi-Carbonate (HCO_3^{-}). Physical parameters such as pH, TDS and EC were determined at on sites with a digital portable water analyser kit (Model Number: EZ9908). For the remaining analysis, every sample was stored in two sterile and dried polypropylene bottles of 500 ml each. One bottle from every sample was bought to the laboratory of DPHE Laboratory, Dhaka to evaluate Sodium (Na^{+}), Potassium (K^{+}) in each, by ASS. Another bottle from every sample was bought to the laboratory of CRTC Laboratory, Department of Civil & Environmental Engineering, SUST, Sylhet to analyse the rests. The test results were examined are presented in Table 1.

Table 1: Ionic variation of hydrochemical parameters of groundwater samples*.

ID	EC at 25ºC (mmohs/cm)	TDS	pH	K^+	Na^+	Mg^{2+}	Ca^{2+}	Cl^-	SO_4^{2-}	CO_3^{2-}	HCO_3^-	NO_3^-
P1	83	50	6.2	2.07	6	36.25	10.82	24	8	ND	42	0.5
P2	28	17	5.7	1.78	5	41.38	13.7	47	1.0	ND	74	0.7
P3	142	85	7.2	1.12	10	26.90	5.29	32	0.0	ND	55	0.8
P4	156	94	7.1	0.82	8	39.26	8.42	44	5	ND	71	1.1
P5	128	77	7.2	1.60	7	23.81	6.01	35	0.0	ND	72	0.4
P6	320	192	7.3	0.90	17	25.13	10.58	27	0	ND	142	0.2
P7	313	188	7.3	1.34	21	21.76	8.42	35	0	ND	144	0.6
P8	311	187	7.4	1.05	26	24.78	12.02	32	0	ND	145	0.5
P9	296	178	7.4	1.00	21	35.18	7.21	40	0	ND	144	0.4
P10	176	106	7.3	1.51	16	30.20	7.69	34	4	ND	109	0.7
P11	321	193	6.8	2.19	13	21.61	4.81	52	5.0	ND	61	1.8
P12	234	140	7.2	1.07	10	35.76	10.82	35	8.0	ND	86	2.2
P13	203	122	7.3	1.13	10	30.81	7.21	25	3.0	ND	97	1.0
P14	152	91	7.4	1.29	7	25.20	12.26	37	0.0	ND	76	1.6
P15	129	77	7.3	1.34	6	20	7.69	37	0.0	ND	72	0.6
P16	189	113	7.1	1.12	7	19.73	4.81	32	0	ND	75	0.8
P17	166	99	7.3	1.68	6	24.6	6.73	24	0	ND	56	0.1
P18	198	119	7.3	0.89	4	35.33	10.58	21	1	ND	99	1.3
P19	194	116	7.3	1.11	19	26.66	6.49	74	1	ND	88	0.9
P20	274	164	7.0	2.18	10	24.31	7.93	57	0	ND	46	2.8

*All values are in mg/L, except pH and EC in mmohs/cm. *ND* not detected

2.4 Graphical Methods for Hydrochemical Assessment

2.4.1 Stiff diagram

In a Stiff diagram a polygonal shape is created from four parallel horizontal axes extending on either side of a vertical zero axis. For a water sample, cations are plotted in milliequivalents per litre on the left side of the zero axis, one to each horizontal axis. Similarly, for the same sample, anions are also plotted in milliequivalents per litre on the right side, one to each horizontal axis. Stiff patterns are useful in making a rapid visual comparison between water from different sources.

2.4.2 Gibbs Diagram

Several factors control the chemistry of groundwater that can be related to the physical conditions of aquifer, bedrock mineralogy and weather condition. Gibbs Diagram helps to identify these controlling factors. The TDS vs. $Na^{+}/(Na^{+}+Ca^{2+})$ and TDS vs. $Cl^{-}/(Cl^{-}+HCO_3^{-})$ scatter plot are used to identify the occurrence of rock-water interaction processes (Gibbs, 1970) i.e. to identify the mechanisms that controlling the water chemistry. The diagram is divided into three fields, the rock-water interaction, precipitation and evaporation. In such diagrams, the samples lying at the centre of the curve indicate a source from the rock-water interaction.

2.4.3 Schoeller diagram

The Schoeller diagram is a histogram-type of diagram showing the log concentrations of solutes (the minor's component in a solution, dissolved in the solvent) in meq/L from a number of samples and shows the effects of mixing of waters. It is a semi-logarithmic plot, in which on the abscissa (on arithmetic scale), the various cations and anions are arranged in the order. In a typical Schoeller diagram, the concentrations of the main ionic constituents of each water sample (SO_4^{2-}, HCO_3^-, Cl^-, Mg^{2+}, Ca^{2+}, Na^+/K^+) in meq/L are plotted on six equally spaced logarithmic scales, and points so plotted are then joined by straight lines. This diagram gives absolute concentration of different ions and not their relative concentration and, in addition, the concentration differences among various samples of groundwater.

2.4.4 Wilcox's diagram

For judging the suitability of water quality for irrigation, Wilcox proposed a diagram with respect to a combination of EC and the sodium percentage (%Na^+). This combination classifies the diagram into five zones of excellent too good with EC values less than 700 mmohs/cm (<700 mmohs/cm), good to permissible, permissible to doubtful, doubtful to unsuitable and unsuitable, with increasing salinity hazard and sodium hazard for irrigation.

2.4.5 US Salinity Laboratory (USSL) Diagram

This diagram was suggested by Wilcox and US Salinity Laboratory staff to evaluate the suitability of water for irrigation use. There is a significant correlation between the sodium adsorption ratio (SAR) values for irrigation water and the amount of sodium absorbed by the soil. The structure of the soil is due to the dispersion of clay particles, which can destroy if the water is high in sodium and low in calcium, which is used for irrigation purposes then the water is complex in cation exchange and can be saturated with sodium. USSL proposed an important criterion based on salinity and sodium hazards. The total dissolved solids, measured in terms of specific electrical conductance (EC), gives the salinity hazard of irrigation water. In addition to the risk of salinity, excess of sodium ions in water make it unsuitable for exchangeable calcium and magnesium ionized soils. If the percentage of Na^+ to Ca^{2+} + Mg^{2+} is considerably above 50 in the irrigation water, soils containing exchangeable calcium and magnesium take up sodium in exchange for calcium and magnesium causing deflocculating and impairment of the tilth and permeability of soils. The sodium hazard in irrigation water is evaluated by determining SAR, which is given as

$$SAR = \frac{Na}{\sqrt{(Ca + Mg)/2}}$$

where the concentrations are expressed in meq/L.

3. RESULTS AND DISCUSSION

3.1 Reliability Checking for Hydrochemical Data

All collected ions from each pump/sample are presented in Table 2 in meq/L. In a water sample, in terms of meq/L, the total of major cations is supposed to be equal to the total of major anions.

Table 2: Ions in millirquivalents per liter (meq/L)

	Cations (meq/L)				Anions (meq/L)				
ID	**K^+**	**Na^+**	**Mg^{2+}**	**Ca^{2+}**	**Cl^-**	**SO_4^{2-}**	**CO_3^{2-}**	**HCO_3^-**	**NO_3^-**
P1	0.0529	0.2610	2.9830	0.5399	0.6770	0.1666	ND	0.6883	0.0109
P2	0.0455	0.2175	3.4050	0.6837	1.3260	0.0208	ND	1.2130	0.0152
P3	0.0287	0.4350	2.2140	0.2640	0.9026	0.0000	ND	0.9018	0.0174
P4	0.0210	0.3480	3.2310	0.4202	1.2410	0.1041	ND	1.1640	0.0239
P5	0.0409	0.3045	1.5950	0.2999	0.9872	0.0000	ND	1.1800	0.0087
P6	0.0230	0.7391	2.068	0.528	0.7616	0.0000	ND	2.3279	0.0043
P7	0.0343	0.9130	1.7910	0.4202	0.9872	0.0000	ND	2.3607	0.0130
P8	0.0269	1.1310	2.0390	0.5998	0.9026	0.0000	ND	2.3770	0.0109
P9	0.0256	0.9130	2.8950	0.3598	1.1280	0.0000	ND	2.3607	0.0087
P10	0.0386	0.6960	2.4850	0.3838	0.9590	0.0833	ND	1.7860	0.0152
P11	0.0560	0.5655	1.7780	0.2400	1.4670	0.1041	ND	0.9997	0.0391
P12	0.0274	0.4350	2.9430	0.5399	0.9872	0.1667	ND	1.4090	0.0478
P13	0.0289	0.4350	2.5350	0.3598	0.7052	0.0625	ND	1.5900	0.0217
P14	0.0330	0.3045	2.0740	0.6118	1.0440	0.0000	ND	1.2460	0.0348
P15	0.0343	0.2610	1.6460	0.3838	1.0440	0.0000	ND	1.1800	0.0130
P16	0.0287	0.3045	1.6240	0.2400	0.9026	0.0000	ND	1.2290	0.0174
P17	0.0430	0.2610	2.0240	0.3358	0.6770	0.0000	ND	0.9178	0.0022
P18	0.0228	0.1740	2.9070	0.5280	0.5923	0.0208	ND	1.6220	0.0283
P19	0.0284	0.8265	2.1940	0.3239	2.0870	0.0208	ND	1.4420	0.0196
P20	0.0558	0.4350	2.0000	0.3957	1.6080	0.0000	ND	0.7539	0.0609

However, an acceptable analysis may have a difference that is less than 10%. Unfortunately, in this study only 10 out of 20 water samples fulfilled the acceptable requirement of < 10%. While the most charge balance errors (CBE) of waters from various locations were sensible, it was too extreme for pump-1, which was way off with 42.64% (Table 3). This might identify the imprecision of the lab analysis, lack of ions or metals analysed. However, electrical imbalance may be due to the fact that the dissolved species of elements or compound that are buffering in minerals of the area might not be included in ions balance calculation. Despite these obvious discrepancies, the data provided in this study are of original. Hence, further studies are needed for proper understanding of the chemical composition of groundwater of SCC area. Nevertheless, the current study is one of the very first researches to interface hydro chemical techniques in groundwater quality analysis in Sylhet City Corporation.

Table 3: Charge balance errors of various water samples\

ID	**∑Cations (meq/L)**	**∑Anions (meq/L)**	**CBE (%)**	**Data Quality**	**ID**	**∑Cations (meq/L)**	**∑Anions (meq/L)**	**CBE (%)**	**Data Quality**
P1	3.8368	1.5428	42.64	Poor	**P11**	2.6395	2.6099	0.56	Good
P2	4.3517	2.575	25.65	Poor	**P12**	3.9453	2.6107	20.36	Poor
P3	2.9417	1.8218	23.51	Poor	**P13**	3.3587	2.3794	17.07	Poor
P4	4.0202	2.533	22.69	Poor	**P14**	3.0233	2.3248	13.06	Poor
P5	2.2403	2.1759	1.46	Good	**P15**	2.3251	2.237	1.93	Good
P6	3.3581	3.0938	4.10	Good	**P16**	2.1972	2.149	1.11	Good
P7	3.1585	3.3609	-3.10	Good	**P17**	2.6638	1.597	25.04	Poor
P8	3.7967	3.2905	7.14	Good	**P18**	3.6318	2.2634	23.21	Poor
P9	4.1934	3.4974	9.05	Good	**P19**	3.3728	3.5694	-2.83	Good
P10	3.6034	2.8435	11.79	Poor	**P20**	2.8865	2.4228	8.73	Good

3.2 Display of Water Quality Data

3.2.1 Stiff Diagram

The plots of major ions (based on meq/L) are presented in Figure 3 with Stiff diagrams, which clearly illustrate the ionic (cationic and anionic) dominance pattern of different water sources/pumps. It is obvious that Mg^{2+} among cations and Cl^- and/or HCO_3^- among anions dominate in almost all the samples of groundwater. However, in a board aspect, the Mg-Na-Ca-Cl-HCO_3 hydrochemical facies is dominant in the groundwater of SCC area.

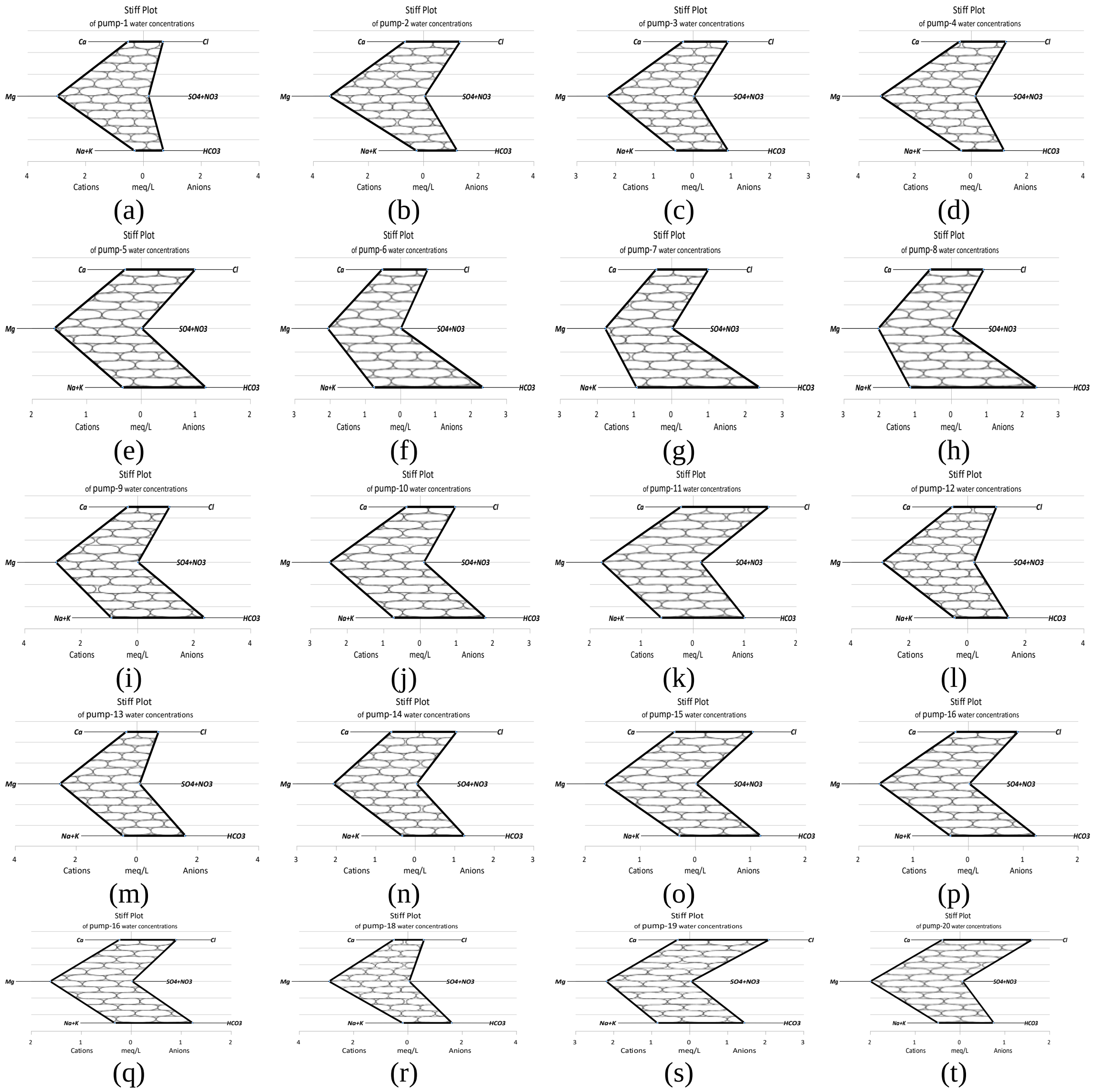
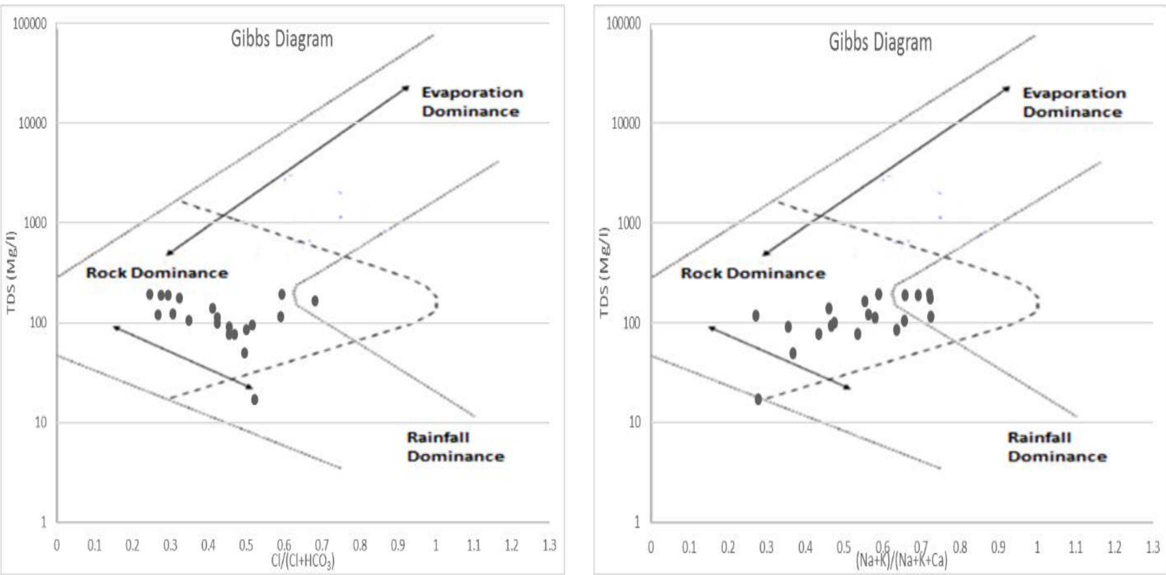


Figure 3: Stiff diagrams for all selected pumps.

3.2.2 Gibbs Diagram

Figure 4(a) and 4(b) represent Gibbs TDS vs. Na^+/ (Na^+ + Ca^{2+}) and TDS vs. Cl^-/ (Cl^-+HCO_3^-) scatter plots plotted using groundwater samples from the study area. The figures show that almost all the samples fall in the rock area. The Gibbs's diagrams suggest that chemical weathering of the rock forming minerals is the main processes that contribute the ions to the water in the study area. It is interesting to note that during pre-monsoon, precipitation has no dominating effect and no point falls on the precipitation dominating area. As the water quality data were collected from the selected pumps during the pre-monsoon season in March 2019, the conclusion from this diagram is more practical. Anthropogenic activities may also increase the TDS value (Hem, 1985) and then the samples tend to fall on evaporation dominance area. However, this is not the case in this study area. It contradicts with the finding from stiff diagrams that indicated anthropogenic activities have influence on the quality of ground water. It may for the fact that the cation Mg^{2+} is not considered here, which is the main dominant cation in the SCC area.



(a) (b)

Figure 4: Gibbs plot for cations and anions in the study area

3.2.3 Schoeller Diagram

The Schoeller diagram in Figure 5 shows the log concentrations of ions SO_4^{2-}, HCO_3^-, Cl^-, Mg^{2+}, Ca^{2+} and Na^++K^+ in meq/L from the samples. It shows that, except and SO_4^{2-}, the selected waters are generally high in Ca^{2+}, HCO_3^-, Cl^-, Na^++K^+ concentrations, it is reflecting the possible mixing of the deep aquifers with the groundwater. All the water samples exhibit a unique pattern and similar “fingerprints”.

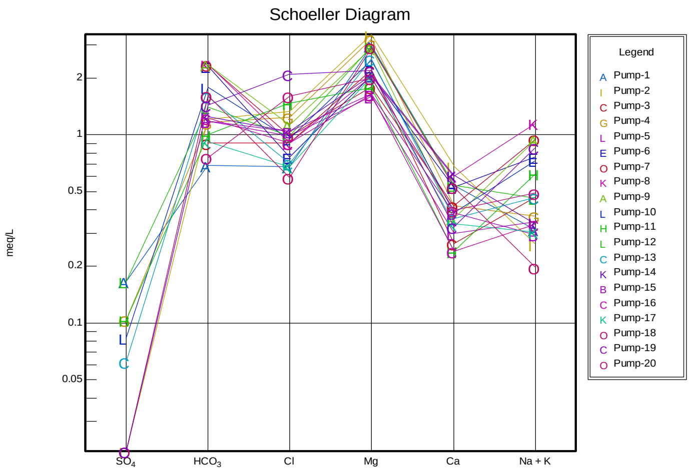


Figure 5: Chemical analysis of ground water plotted on the schoeller diagram

3.2.4 Wilcox's Diagram

As shown in Figure 6, the wilcox's diagram indicates that all of the groundwater samples fall in the fields of very good to good. Thus, the dwellers of the city can easily and effectively use the supplied water for irrigation purposes.

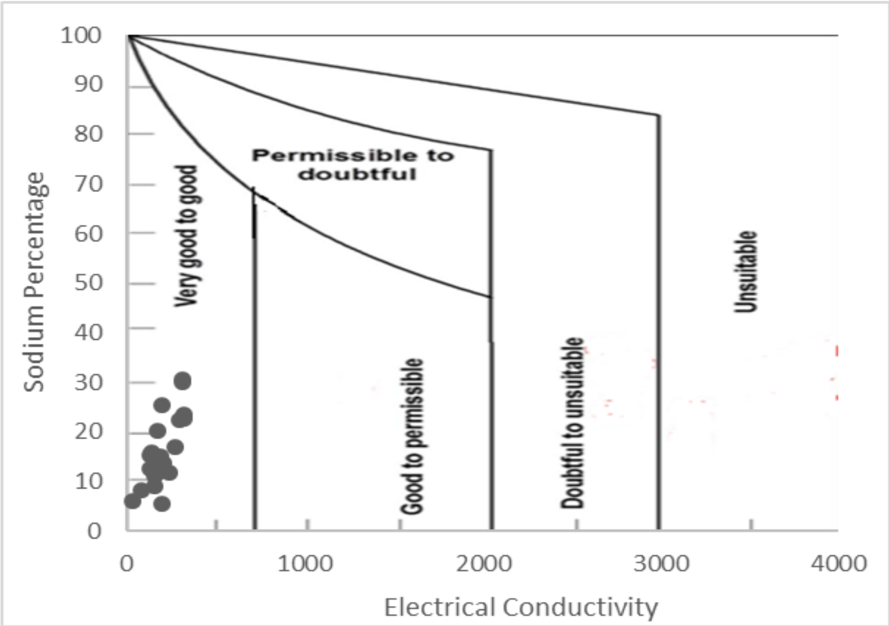


Figure 6: Wilcox's classification of groundwater quality for irrigation

3.2.5 US Salinity Laboratory (USSL) Diagram

From the below figure of USSL diagram, it is identified that 20 water samples (100%) of pre-monsoon seasons belongs to C1-S1 and C2-S1 types and suggesting that the groundwater of SCC area is good for irrigation purposes.

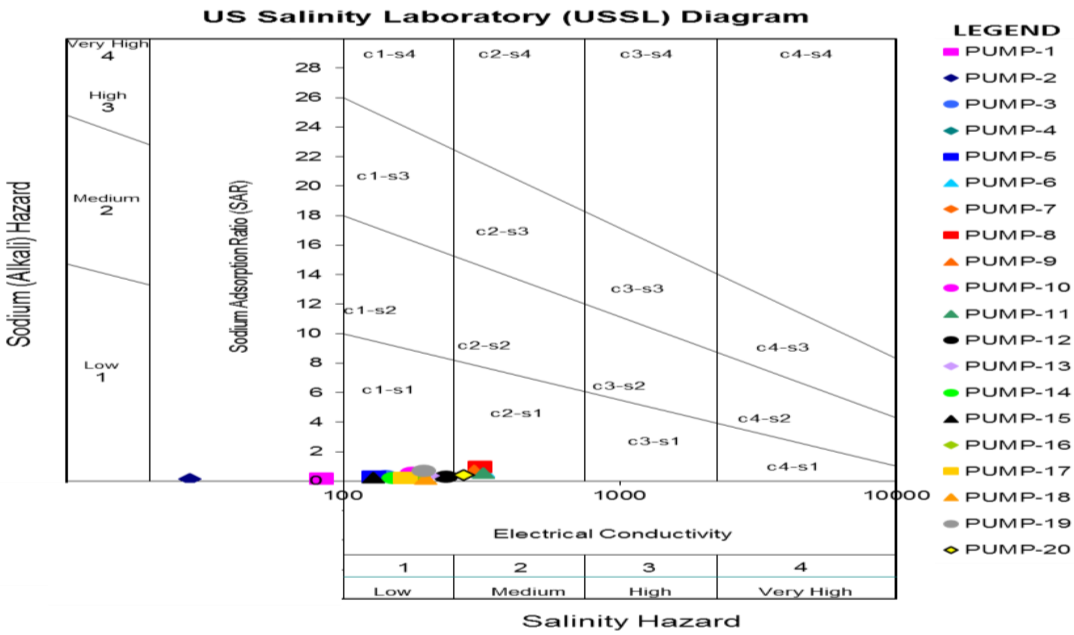


Figure 7: USSL diagram for classification of groundwater quality for irrigation

4. CONCLUSIONS

All the selected groundwater samples are dominated by Mg^{2+} among cations and Cl^- and/or HCO_3^- among anions. In a board aspect, Mg-Na-Ca-Cl-HCO_3 is the hydrochemical facies that dominates in the groundwater of SCC area. The fossil and mineralogical groundwater characterizes the Mg-Na-Ca-Cl facies in the middle part of the city, whereas the Mg-Na-Ca-HCO_3 facies in the western part which is linked with recently recharge water of $CaHCO_3$ type, atmospheric precipitation and dissolution of silicate minerals. The Gibbs's diagrams suggest that chemical weathering of the rock forming minerals is the main processes that contribute the ions to the pre-monsoon water in the study area. Almost all the water samples exhibit a unique pattern and similar “fingerprints”. EC (salinity hazard), Sodium percent (Na%) and Sodium adsorption ratio (SAR) were used to assess the water quality for irrigation purposes. The water in the study area have been found very well for irrigation. Urbanization and agricultural activities are not responsible for water quality. This is because nitrate and sodium absorption ratios present in the study area are not high.

5. LIMITATIONS AND FURTUR STUDY

About 50% of the samples data (10 out of 20) have not passed the quality control tests, major ionic balance that is necessary for using classical hydrochemical plotting. Thus, some findings might be questioned. To ensure utmost reliability and validity in conducting a laboratory-based study on hydrochemical properties of water, a large sample size is required, which is absent in here. The direction of groundwater flow could not be fully assessed, because of inadequate data. Frequent monitoring of the pumps is also required for proper evaluation. This is not possible in this study. No comparison was made between the quality of groundwater and surface water, which is necessary for proper evaluation. There is no opportunity to compare the present study with others. This is because of the absence of available studies in SCC area that are in the line of this work. As this study aimed at to gain some knowledge about the underlying hydrochemical interactions, it has not yet investigated other approaches e.g. supervised classification techniques, state-of-the-art chemometrics techniques or pattern recognition processes including multiple linear regression (MLR), multivariate analysis, etc. As the continuation of current study, a further study will immediately be done using multivariate techniques.

6. RECOMMENDATIONS

The overall quality of groundwater is not harmful but continuous evaluation is necessary for proper maintenance. Because of continuous exploitation of groundwater for domestic uses and drinking purposes, the rock-forming minerals continue to dissolve; thereby there is a risk of resulting in a continuous increase in the TDS content of the study area. So, the alternative sources for water should be searched. It is suggested to use surface water with proper treatment. The absence of a reliable sewer collecting system directly resulted in the poor water quality in SCC area. Such a sewer collecting system should be developed. This will help to avoid anthropogenic effects. A detailed study is needed based on all possible parameters and all pumps under SCC. The study area is covered by different geological formations. Therefore, a detailed study with mineral and chemical composition of the rocks is further needed. Future studies should incorporate hydrological parameters into the chemical assessment e.g. water levels, thermal profiles, depth profiles (this was attempted in the field but not successful). Some of the pumps are maintained by government who have a limited budget. So, one option may be handover the pumps to private institutions, NGO's for batter maintenance.

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