Assessment of groundwater quality and determination of hydrochemical evolution of groundwater in Shillong, Meghalaya (India)

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Abstract

Deterioration of surface water quality in various parts of India due to increasing urbanization has led to the extensive usage of groundwater for various domestic and irrigation needs, thereby raising concerns over its quality. However, there are very few studies focussing over the issue of groundwater quality in North-Eastern region of India. In order to make an assessment of the quality of groundwater for drinking and irrigation purposes, this study was carried out in Shillong—the Capital City of Meghalaya State in North-East India during pre-monsoon and post-monsoon seasons of 2018. Standard sampling and analytical procedures were followed for groundwater quality assessment. Minimal variation was observed in the water quality of pre- and post-monsoon seasons. However, the study found that groundwater samples are having acidic pH and presence of nitrate is also reported. Some of the samples also showed the presence of mercury, nickel, and cadmium. The presence of these contaminants could be attributed to the industrial activities in the state. Overall, the groundwater quality was found suitable for drinking and irrigation purposes after conventional treatment. Hydrochemical studies further inferred that groundwater properties in the region are influenced by the rock weathering along with the atmospheric precipitation.

1 Introduction

Periodic water quality assessment of surface and groundwater is necessary for the well-being of ecosystem in general, and for the human society in particular. Declining surface water resources along with the increasing levels of pollution have rendered the use of groundwater mandatory in various parts of the globe [1, 2]. Being the largest user of the groundwater in the world, India fulfils its 85% drinking water needs and more than 60% of the irrigation requirements through groundwater resources [3, 4]. Therefore, it is of utmost importance to look after the groundwater resources on regular basis so that required

action, if any, could be taken well in time. The chemical constituents of the water are affected by natural as well as anthropogenic factors. Increasing use of chemicals (fertilizers and pesticides) for the agricultural practices is also one of the anthropogenic causes for the deterioration of both surface and ground water quality [5]. Therefore, it is necessary to keep a check on the water quality in order to ensure wellbeing of the people.

Considering the importance of groundwater and its quality degradation due to urbanization and increasing pollution, many researchers have discussed the groundwater chemistry and its human health risk assessment across the globe [6–9]. Not only the heavy metals and

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bacterial contamination, excess amount of basic water quality parameters such as pH, total dissolved solids, and nitrate have also been reported in groundwater owing to unsustainable use and indiscriminate subsurface discharge of various pollutants [4, 7]. In order to understand the effects of these factors onto the health and agriculture, many researchers have employed various statistical and multivariate statistical analyses tools [1]. As water quality index is a comprehensive approach to assess the quality of groundwater, Su et al. have used entropy weighted water quality index [10]. Use of Fuzzy method has also been reported by the researchers for the easy and accurate estimation of water quality [7].

Groundwater is affected by various other factors as well, such as geological features, precipitation pattern, rock weathering mechanism, river system, oxidation–reduction, evaporation, sorption, and exchange reactions [11, 12]. The water quality of Shillong is also affected by various such processes. Meghalaya, a north-eastern hilly state, is one of the 29 states of India bounded to the south by Bangladeshi divisions, and to the north and east by Assam, India. This state is the wettest region of India, receiving approximately 12,000 mm rain in a year. Therefore, it is obvious that the groundwater chemistry of the area

would show the influence of the rainfall pattern of the area. The present study was carried out in Shillong, which was known as the 'Scotland of the East' during British period owing to the presence of rolling hills around the town [13]. Although this region has been pollution free, the population explosion and urbanization have led to various environmental problems recently. Surface water scarcity is among one of those problems which is of serious concern due to topography of the region [14]. Due to shortage of the clean surface water, now the pressure is increasing onto the groundwater resources, and hence, it was considered necessary to have an assessment of the quality of the same. In this manuscript, the assessment and suitability of the groundwater in the Shillong region for drinking and irrigation purposes are detailed.

2 Materials and methods

2.1 Study area

This study was carried out in Shillong which is the capital city of Meghalaya State in India (Fig. 1). Shillong is also the district headquarter of East Khasi Hills (2748 km^2), which is
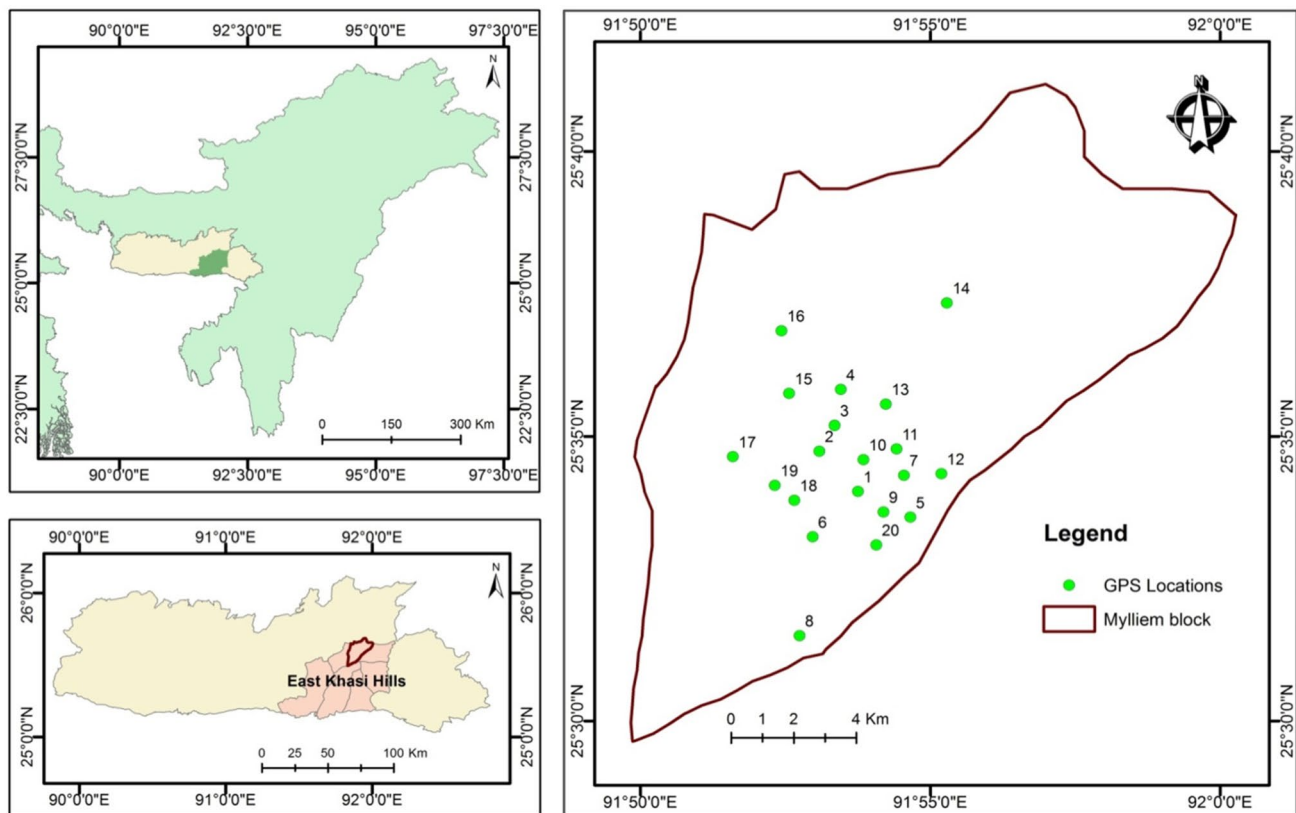

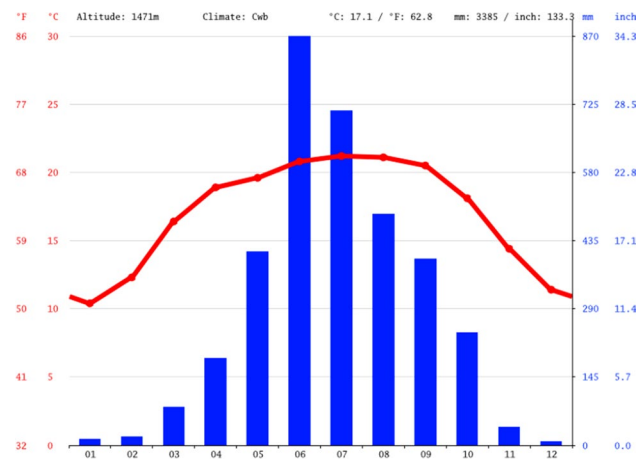**Fig. 1** Location of Shillong and sampling sites

Fig. 2 The annual climate distribution (rainfall and temperature) map of Shillong. *Source:* https://en.climate-data.org/asia/india/meghalaya/shillong-24618/#climate-graph

one of the seven districts of Meghalaya State. The climate of the area ranges from temperate humid to subtropical humid with temperature varying from 1.7 °C to 24 °C [14]. Annual climate distribution of the district is shown in Fig. 2. It depicts that the highest rainfall in the area is received in the month of June and July, though none of the month is completely dry. The highest temperature is also reported in the same months, thus making the climate humid. The south-west monsoon, which originates from the Bay of Bengal, has large effect on the weather pattern in Meghalaya. It results in heavy rainfall of more than 12,000 mm in various districts of the state. Mawsynram, which receives about 12,270 mm rainfall, is the wettest place on the earth owing to the specific geographical and climatological conditions. Shillong is also characterized by the presence of a number of rivers, such as Umtrew, Umiam, Umkhen in the northern parts and Umiew (Shella), Umngot, Umngi (Balat) in the southern part. The rivers present in the northern part of the district drain into the Brahmaputra River (India), while southern rivers drain into the Surma River (Bangladesh) [14].

Precambrian rocks of gneissic composition are the dominant rock types in the study area. Basically, these rocks form the base of the overlying Shillong rocks. Another rock type which is present in the study area is quartzite. These quartzites attained their final form after the metamorphosis, though originally these are of sedimentary origin, as evident by the presence of bedding and ripple marks. As the terrain in Shillong is mountainous and undulating, the groundwater resources in the area are influenced by the topography, presence of rock fractures, and weathering zones. Generally, the groundwater in the region is found in the weathered and fractured zone of quartzite, under the water table condition. Groundwater resources have

been reported in the form of springs, seepages, wells, and bore wells. The property of retaining water in the bore wells is also influenced by the underlying rocks, as it has been seen that metabasic rocks provide better inflow of groundwater. Consequently, the wells over the metabasic rocks have water availability throughout the year, while the wells over the quartzites become devoid of water in dry season. The hydrogeological map of East Khasi Hills District of Meghalaya is shown in Fig. 3, which shows that the highest groundwater potential is in the coarse sandstone, silt, shale, and clay formations, though their occurrence is limited. The majority of the area is occupied by the quartzite and granite rocks having groundwater potential of 5–15 m^3/hr.
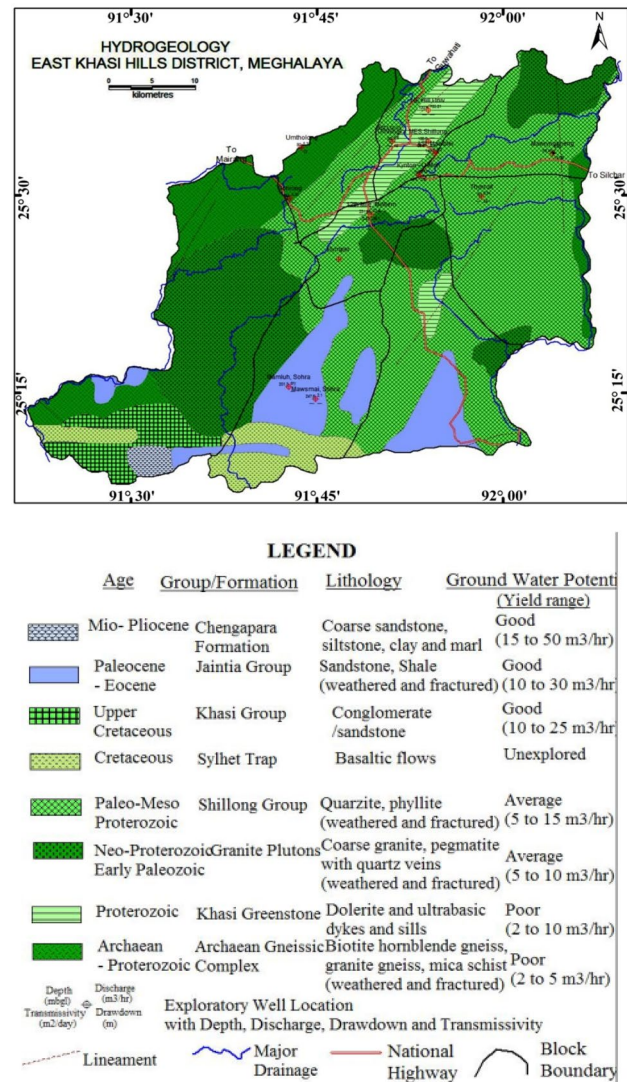

Fig. 3 Hydrogeological map of East Khasi Hills District, Meghalaya. *Source: CGWB 2013* [14]

2.2 Sampling and preservation

Twenty ground water samples were collected each during pre- and post-monsoon seasons of 2018. The details of the sampling locations are shown in Table 1. The sampling points are located in the middle of the basin as the northeast and southwest parts of the study region were forests/hilly areas and hence not accessible (Fig. 1). The samples were collected from bore wells in clean polyethylene bottles, and acid was added in order to preserve [4, 15, 16]. The water samples for trace element analysis were collected in acid leached polyethylene bottles and preserved by adding ultra-pure nitric acid (5 mL/lit.). All the samples were stored in sampling kits maintained at 4 °C and brought to the laboratory for detailed physico-chemical analysis. The distribution of sampling locations is shown in Fig. 1.

2.3 Analysis

All the chemicals used for the analysis were of analytical grade (Merck). To analyse the metal content in the samples, standard solutions of metal ions were procured from Merck, Germany. De-ionized water was used for the analysis. Samples for metal analysis were filtered using 0.45 μm membrane filter. Glasswares and all other containers used for trace element analysis were thoroughly cleaned using appropriate methods [4].

Prescribed standard methods were used for the analysis of physico-chemical parameters [15, 16]. The analysis of anions and cations was carried out using Ion Chromatograph (IC) (Make: Metrohm, Model 930). Metal analysis was done in Inductively Coupled Plasma Mass Spectroscopy (ICP-MS) (Make: PerkinElmer, Model: ELAN DRC-e). For bicarbonate analysis, Potentiometric Auto Titrator (Model 888 system) was used. Analytical precision was < 5% for all the analytes (anions and cations) and metals, and accuracy was < 5%. Alkalinity was determined by setting the end point using Potentiometric Auto Titrator, and finally, bicarbonate was calculated using inbuilt formula in the system (titration accuracy < 2.0%, precision < 1.5% and systemic error < ± 0.010 mL). Errors in ionic balance were < 5% for each analysis. Ionic balance was calculated by the formula $[\{(TZ^+ - TZ^-)/(TZ^+ + TZ^-)\} \times 100]$, thus establishing the reliability and quality of the analytical results. Calibration curves of standard solutions for the respective constituents were drawn for the quantification of chemical constituents. AQUACHEM 2011.1 software was used for drawing the Piper plot.

Table 1 Groundwater sampling locations in Shillong

S. No	Location	Geographical coordinates		Source	Depth (m)	Yield (L/hr)	Land use
		Latitude	Longitude				
1	Gordon road, Bhagyakul, Laitumkhrah	25°34′2″	91°53′45.1″	Bore well	198	2500	Domestic
2	Jail road	25°34′44.6″	91°53′5.1″	Bore well	50	5000	Domestic
3	Forest colony	25°35′11.6″	91°53′20.9″	Bore well	61	1500	Domestic
4	Mawlaidatbaki pata block A	25°35′82.1″	91°53′45.7″	Bore well	84	4800	Domestic
5	Evangelical free church, Demthring, PO: Madanryting	25°33′34.9″	91°54′39.3″	Bore well	46	2000	Domestic
6	Happy valley	25°33′14.1″	91°52′58.3″	Bore well	69	1500	Domestic
7	Law U Sib, Divine grace cottage	25°33′47.0″	91°54′46.7″	Bore well	97	2000	Domestic
8	Laitkor, Lumheh Mawrie	25°31′4.20″	91°52′46.78″	Bore well	100	2500	Commercial
9	Nongrim hills	25°33′58.1″	91°54′3.8″	Bore well	245	5000	Commercial
10	Laitumkhrah	25°34′16.8″	91°53′48.2″	Bore well	198	4800	Commercial
11	Fruit garden	25°33′56.2″	91°53′45.9″	Bore well	143	11,250	Commercial
12	Lapalang dong parmaw	25°34′16.6″	91°55′37.7″	Bore well	125	4500	Domestic
13	Bellefonte, Lumshyiap	25°35′33.9″	91°54′14.0″	Bore well	37	2000	Domestic
14	Mawtawar Lummawsing	25°37′20.5″	91°55′17.2″	Bore well	183	500	Domestic
15	Mawlai Syllaikariah	25°35′45.1″	91°52′33.9″	Bore well	100	2000	Domestic
16	Mawiong umjapung block nongneng-A	25°36′51.1″	91°52′25.9″	Bore well	132	2000	Domestic
17	3rd Mile upper Shillong	25°34′38.7″	91°51′35.6″	Bore well	92	1200	Domestic
18	Howell road near shiv mandir, Laban	25°33′52.7″	91°52′39.1″	Bore well	43	2000	Domestic
19	Behind Shillong times	25°34′8.6″	91°52′19.1″	Bore well	85	1000	Domestic
20	Nongthymmai, Dum Dum	25°33′48.5″	91°54′36.8″	Bore well	41	3000	Domestic

3 Results and discussion

3.1 Groundwater quality evaluation for drinking purposes

Groundwater quality estimation in Shillong was done for all the necessary organoleptic and physico-chemical parameters. The metals were analysed only for the samples collected during pre-monsoon. Tested values were compared with the standard values given by Bureau of Indian Standards (BIS) and World Health Organization (WHO) [17, 18] (Tables 2–3). It can be seen that among the general parameters, nitrate (NO_3^-) is the only parameter for which the value is exceeding the acceptable limit. Another parameter of interest is pH. As per the BIS and WHO, the acceptable pH values for drinking purposes should lie within the range of 6.5–8.5. It was seen that none of the samples were having pH value beyond 8.5; however, 12 samples recorded the value below 6.5, minimum being the 3.5. It indicates acidic contamination in the groundwater. One of the reasons for this acidic contamination might be the influence of geological factors of the area. Meghalaya is known for the high deposits of coal [19], and Indian coal is characterized by the high sulphide pyrite content [20]. Moreover, the geology

Table 2 General parameters with respect to drinking water quality in Shillong and comparison with standards [17, 18]

| Water quality parameters	WHO standard*		Indian standard (BIS)*		Water quality in Shillong*			Number of samples beyond acceptable limit	Number of samples beyond permissible limit
	Max. desirable limit	Max. permissible limit	Acceptable limit	Permissible limit	Min	Max	Mean		
Pre-monsoon									
pH	–	6.5–8.5	6.5–8.5	–	3.5	8.0	5.95	12	0
Conductivity	–	–	–	–	12.2	759	214	–	–
TDS	500	1500	500	2000	7.8	486	137	0	0
Alkalinity	–	–	200	600	Nil	96	21	0	0
Hardness	100	500	200	600	6.3	156	53	0	0
Sodium	–	–	–	–	0.5	59	13	–	–
Potassium	–	–	–	–	0.3	27	4.2	–	–
Calcium	75	–	75	200	1.99	44	15	0	0
Magnesium	50	150	30	100	0.20	16	3.6	0	0
Chloride	250	–	250	1000	0.43	81	21	0	0
Sulphate	–	–	200	400	0.09	39	9.9	0	0
Nitrate	–	–	45	–	0.14	186	31	5	–
Fluoride	1.0	1.5	1	1.5	0.02	0.42	0.09	0	0
Boron	–	2.4	0.5	1	0.01	0.03	0.02	0	0
Post-monsoon									
pH	–	6.5–8.5	6.5–8.5	–	4.1	7.8	6.1	9	0
Conductivity	–	–	–	–	20.9	710	183	–	–
TDS	500	1500	500	2000	13.4	454	117	0	0
Alkalinity	–	–	200	600	Nil	108	21	0	0
Hardness	100	500	200	600	9.3	144	43	0	0
Sodium	–	–	–	–	0.57	55	12	–	–
Potassium	–	–	–	–	0.36	24	3.55	–	–
Calcium	75	–	75	200	2.59	33	12	0	0
Magnesium	50	150	30	100	0.40	16	3.17	0	0
Chloride	250	–	250	1000	0.46	75	17	0	0
Sulphate	–	–	200	400	0.11	31	7.35	0	0
Nitrate	–	–	45	–	0.03	165	25	2	–
Fluoride	1.0	1.5	1	1.5	0.01	0.34	0.07	0	0
Boron	–	2.4	0.5	1	0.01	0.03	0.02	0	0

*All values are in mg/L, except for pH and conductivity (µS/cm)

Table 3 Presence of metals with respect to drinking water quality in Shillong district and comparisons with the standards [17, 18]

Metals	WHO standard*		Indian standard (BIS)*		Water quality in Shillong*			Number of samples beyond acceptable limit	Number of samples beyond permissible limit
	Max. desirable limit	Max. permissible limit	Acceptable limit	Permissible limit	Min	Max	Mean		
Iron (Fe)	–	–	300	–	47	6342	986	7	–
Manganese (Mn)	–	500	100	300	10	464	178	12	5
Copper (Cu)	–	1000	50	1500	3	311	52	6	0
Chromium (Cr)	–	–	50	–	0.2	4.7	1.0	0	–
Lead (Pb)	–	50	10	–	0.3	10	3.2	0	–
Arsenic (As)	–	50	10	50	0.06	4.89	0.9	0	0
Mercury (Hg)	–	1	1	–	0.07	9.45	0.9	3	–
Nickel (Ni)	–	–	20	–	1.5	54	7.6	1	–
Zinc (Zn)	–	5000	5000	15,000	19	3356	552	0	0
Cadmium (Cd)	–	5	3	–	0.3	10	3.2	8	–

*All values are in µg/L

of Meghalaya is also characterized by the presence of high iron content [14]. Iron sulphide upon oxidation forms the sulphuric acid (Eqs. 1 and 2) [21], which might increase the acidity of groundwater. Another reason might be the contamination from acid mine drainage [22].

$$4FeS_2 + 11O_2 \rightarrow 2Fe_2O_3 + 8SO_2 \qquad (1)$$

$$2SO_2 + 2H_2O + O_2 \rightarrow 2H_2SO_4 \qquad (2)$$
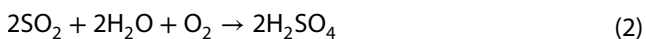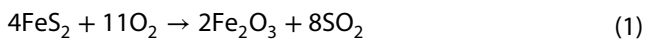
High concentration of nitrate in samples collected from well number 5, 7, 12, 15, and 20 (Table 1) is also indicative of the unhygienic conditions near these wells and contamination due to municipal sewage as it was found flowing through the open drains. There was no diffuse contamination from fertilizers [5]. Contamination due to sewage is of serious concern and needs to be looked upon as it is difficult to restore groundwater quality, once contaminated [7]. The spot value maps for pH and nitrate are presented in Fig. 4.

Analysis of water quality results indicates that most of the sites are common where pH and nitrate values are persistently beyond the acceptable range. High values of nitrate can be attributed to the faecal contamination through the open municipal drains [5].

Further, the analytical results of metals reveal that water quality of the area is affected by the presence of iron (Fe), manganese (Mn), mercury (Hg), nickel (Ni), and cadmium (Cd) to the considerable extent. Among these elements, presence of Fe and Mn can be attributed to local geogenic causes. Low pH in the groundwater might be one of the reasons for the occurrence of high amount of Fe and Mn.

It is a fact that acidic pH results in more dissolution of Fe and Mn [23]. Since in the groundwater of Shillong, pH values are far below the acceptable range and water is acidic (Table 2), the excess amount of Fe and Mn is evident. In such conditions, iron occurs in the form of Fe^{+2}. Such water might result in rusty colour upon bringing it into the atmosphere, owing to the oxidation from Fe^{+2} to Fe^{+3}. The occurrence of Fe and Mn is not much harmful because of their natural presence in human body [4, 24, 25]. However, dissolved iron (Fe^{+2}) results in growth of iron bacteria within the bore wells, which might create problems of unpleasant taste and odour in the bore well waters. Therefore, it is advisable to disinfect the bore wells and plumbing fixtures at regular time intervals. Occurrence of Hg, Ni, and Cd is undoubtedly a reason of concern, considering the harmful impacts onto the human body. These three elements are generally of industrial origin. Though very few samples are exceeding the acceptable limit, the presence of these metals shows that there is seepage either from point or non-point sources, which is contaminating the groundwater. Discharge from open municipal drains could also be one of the reasons for the occurrence of metals. Moreover, the inappropriate disposal from industries manufacturing dry cell batteries, light bulbs, and other fluorescent items also contributes toward the groundwater contamination [22].

3.2 Groundwater quality evaluation for irrigation purposes

For agricultural purposes, it is necessary to evaluate groundwater samples as water of suitable quality is one of the prime requirements for enhancing the crop growth
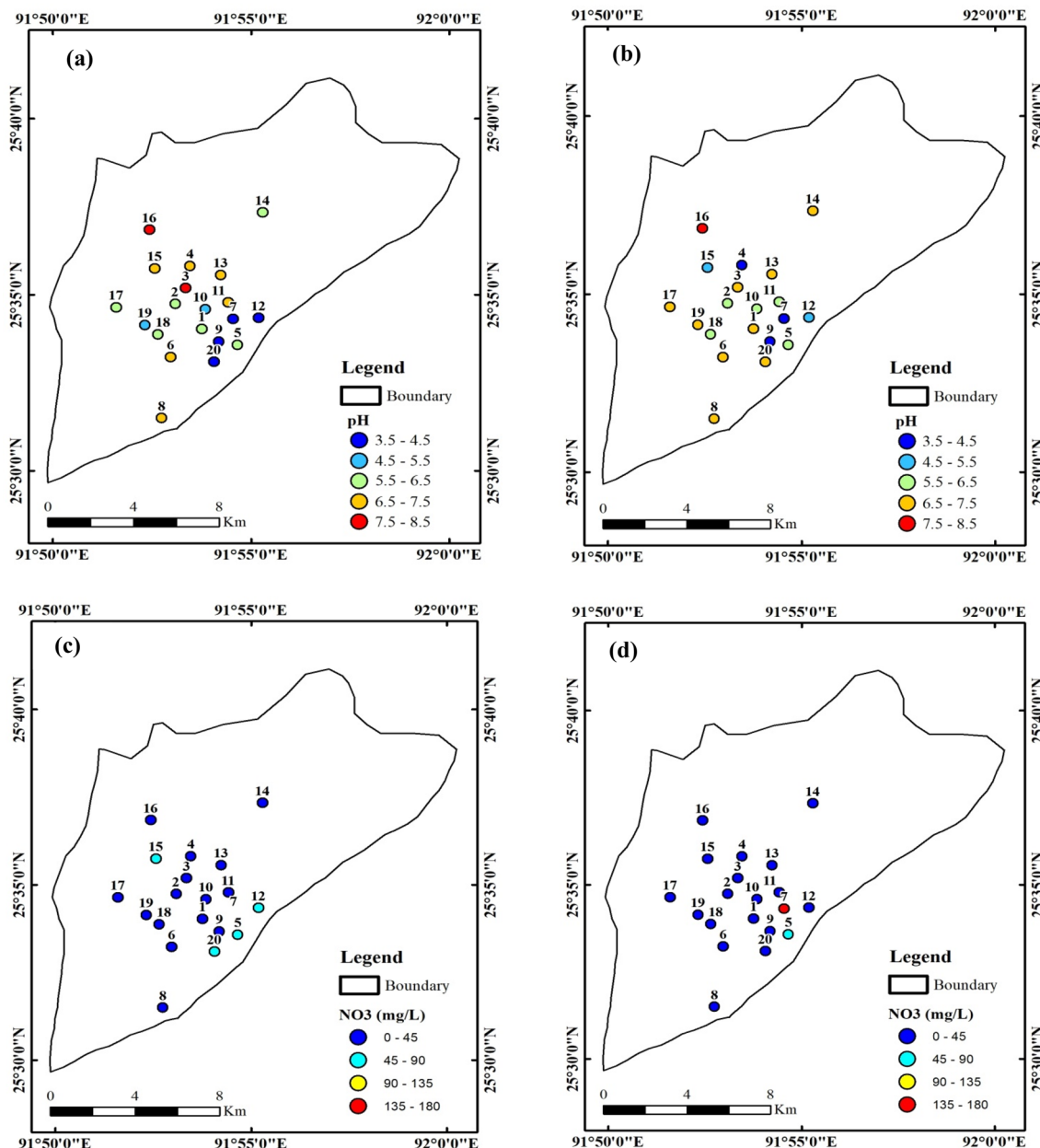
Fig. 4 Spot value maps for the parameters beyond acceptable limits **a** pH (pre-monsoon), **b** pH (post-monsoon), **c** nitrate (pre-monsoon), and **d** nitrate (post-monsoon)

and soil properties [26]. With this purpose, chemical parameters were assessed to determine the quality of water for irrigation purposes (Table 4). Total dissolved solid (TDS) is one of the most important parameters, and its value for all the samples is below the 1000 mg/L, the maximum value being 454.4 mg/L. It represents that the soil is of non-saline nature. Electrical conductivity is another parameter for representing salinity. High conductivity is not considered good as it might lead to high salinity. Table 4 shows that 70% samples are having conductivity < 250 μS/cm, while 25% lies in the range of 250–750 μS/

cm. Therefore, this water is suitable for its use for irrigation purposes in terms of salinity hazard.

Apart from salinity, another important factor to consider for irrigation purposes is the alkalinity. Sodium concentration in the soil affects the sodium absorption ratio. High concentration of sodium results in alkali hazard in the soil. In such conditions, clay particles tend to absorb sodium ion and displace the magnesium and calcium ions. It results in saturation of cation exchange complex with sodium and further leads to dispersion of clay particles, thereby altering the soil structure [4]. Permeability of the

Table 4 Irrigation water quality parameters

Parameters	Range	Classification	Number of samples in Shillong	
			Pre-monsoon	Post-monsoon
Total dissolved solid (TDS) (mg/L) [27]	< 1000	Non-saline	20	20
	1000–3000	Slightly saline	0	0
	3000–10,000	Moderately saline	0	0
	> 10,000	Very saline	0	0
Salinity hazard (EC) (µS/cm) [27]	< 250	Excellent	14	16
	250–750	Good	5	4
	750–2000	Permissible	1	0
	2000–3000	Doubtful	0	0
	> 3000	Unsuitable	0	0
Alkalinity hazard (SAR) [28]	< 10	Excellent	20	20
	10–18	Good	0	0
	18–26	Doubtful	0	0
	> 26	Unsuitable	0	0
Percent sodium (%Na) [29]	< 20	Excellent	3	4
	20–40	Good	8	5
	40–60	Permissible	8	9
	60–80	Doubtful	1	2
	> 80	Unsuitable	0	0
Permeability index (PI) [29]	< 80	Good	18	16
	80–100	Moderate	0	2
	100–120	Poor	2	2
Kelly's ratio (KR) [30]	< 1	Suitable	16	17
	> 1	Unsuitable	4	3
Magnesium ratio (MR) [31]	> 50%	Suitable	2	2
	< 50%	Unsuitable	18	18
Residual sodium carbonate (RSC) [32]	< 1.25	Suitable	20	20
	1.25–2.5	Marginally suitable	0	0
	> 2.5	Unsuitable	0	0
Corrosivity ratio (CR) [33]	< 1	Suitable	11	8
	> 1	Unsuitable	9	12

soil may also get affected by such an exchange of cations [34]. In the present study, alkalinity hazard is less than 10, which indicates that water is suitable for agricultural purposes. As per the permeability index also, majority of the samples lie within the suitable range. Percent Na and Kelly's ratio indicates the sodium content in water. For both these parameters, the values were found within the suitable range (Table 4).

US salinity diagram was plotted for assessing the sodium and salinity hazard, as shown in Fig. 5. A total of 45% pre-monsoon samples lie in C1-S1 category, while 25% samples lie in C2-S1 category. Similarly, among the post-monsoon samples, 50% lie in C1-S1 category and 20% lie in C2-S1 category. C1-S1 category represents the low salinity and low sodium hazard, while C2-S1 category

represents the medium salinity and low sodium hazard [28, 35]. Thus, this analysis corroborates that the groundwater is fit for irrigation purposes. However, it is to be noted that one pre-monsoon sample lies in C3-S1 category as well which indicates high salinity and low sodium hazard. This particular condition may be attributed to local factors. Plants having sufficient salt tolerance may be preferred for cultivation using this groundwater [4].

Magnesium ratio and residual sodium carbonate are also important parameters to determine the alkalinity hazard in the water to be used for irrigation purposes. Kumar et al. reported that alkalinity may increase if the water contains high magnesium content which ultimately affects the yield of the crop [36]. It is intriguing to note that out of the 20 samples in pre-monsoon and post-monsoon seasons
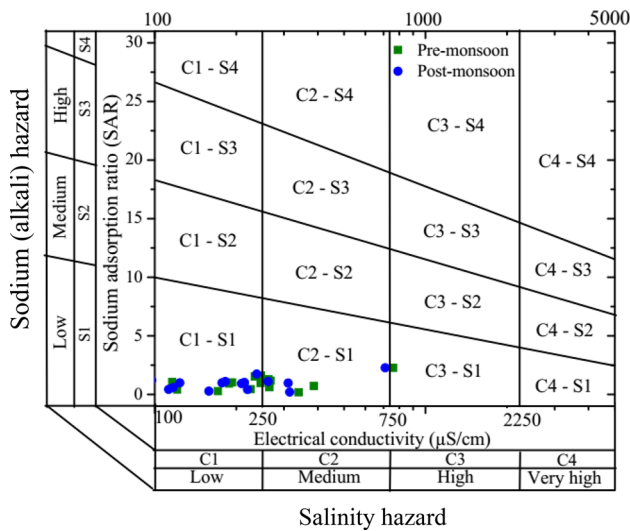
Fig. 5 US salinity diagram for classification of groundwater for irrigation purposes

each, only 2 samples in each seasons were found suitable as far as magnesium ratio is concerned (Table 4). However, in such a case, the soil to be used for cultivation may be treated with some organic/inorganic acidifying materials. Another important parameter of interest is residual sodium carbonate (RSC), which is usually assessed to check the suitability of irrigation water for clayey soil. This is so because clayey soils possess high cation exchange capacity. It can be seen in Table 4 that all the samples are found to be suitable, having RSC values less than 1.25 [32].

Corrosivity ratio is the ratio of alkaline earths to saline salts in groundwater [33] and is usually calculated for determining the suitability of groundwater for its transportation and distribution through metallic pipes. In case water is found to be corrosive for the

pipes, polyvinylchloride (PVC) pipes may be utilized. In the Shillong water, almost half of the samples were found to be corrosive (Table 4), and therefore, use of PVC pipes is advised.

Thus, it can be seen that water quality of the Shillong is suitable for agricultural purposes in respect of all the parameters except magnesium ratio and corrosivity ratio.

3.3 Groundwater chemistry and hydrochemical mechanisms

3.3.1 Correlation among hydrochemical variables

Pearson's correlation matrix is a good method to establish the relationship among various variables. The correlation matrix for pre-monsoon and post-monsoon seasons (Table 5 and Table 6, respectively) shows the inter-relationship among 13 hydrochemical parameters. Excess amount of salt which is dissolved in water (TDS) increases the electricity conducting ability of water, thereby establishing the correlation with EC. Positive correlation of EC also exists with the Na, K, Ca, Cl, etc., in both pre-monsoon and post-monsoon seasons. Further, strong correlation is also seen among the TDS and Na, K, Ca, Cl. Positive correlation is also seen between total hardness (TH) and Ca and Mg. Since hardness is caused by the carbonates and bicarbonates of Ca and Mg, positive correlation among them is evident. It is interesting to note that Cl is strongly correlated with NO_3 in both the seasons. This might be due to the influence of sewage contamination as it was found flowing through the open drains near the sampling sites.

Table 5 Pearson's correlation matrix for groundwater samples—Pre-monsoon#

	pH	EC	TDS	TA	TH	Na	K	Ca	Mg	Cl	SO_4	NO_3	F
pH	1												
EC	−0.22	1											
TDS	−0.22	1.00	1										
TA	0.75	0.19	0.19	1									
TH	0.32	0.79	0.79	0.71	1								
Na	−0.49	**0.90**	**0.90**	−0.21	0.45	1							
K	−0.29	**0.90**	**0.90**	−0.06	0.53	**0.86**	1						
Ca	0.29	**0.80**	**0.80**	0.65	**1.00**	0.51	0.60	1					
Mg	0.28	0.50	0.50	0.64	0.79	0.20	0.22	0.59	1				
Cl	−0.46	**0.90**	**0.90**	−0.17	0.52	**0.97**	**0.81**	0.57	0.27	1			
SO_4	0.03	0.13	0.13	−0.03	0.14	0.02	0.12	0.28	−0.20	0.13	1		
NO_3	−0.47	**0.90**	**0.90**	−0.18	0.48	**0.95**	**0.85**	0.49	0.31	**0.92**	−0.16	1	
F	−0.32	0.70	0.70	0.04	0.46	0.71	0.75	0.42	0.40	0.60	−0.13	0.73	1

#Bold letters depict the strong correlation between the parameters

Table 6 Pearson's correlation matrix for groundwater samples—Post-monsoon[#]

	pH	EC	TDS	TA	TH	Na	K	Ca	Mg	Cl	SO$_4$	NO$_3$	F
pH	1												
EC	−0.38	1											
TDS	−0.38	1.00	1										
TA	0.54	0.08	0.08	1									
TH	0.12	0.77	0.77	0.67	1								
Na	−0.57	**0.90**	**0.90**	−0.26	0.46	1							
K	−0.33	**0.90**	**0.90**	−0.11	0.55	**0.84**	1						
Ca	0.04	**0.80**	**0.80**	0.54	**1.00**	0.57	0.69	1					
Mg	0.22	0.52	0.52	0.78	**0.90**	0.21	0.24	0.76	1				
Cl	−0.54	**0.90**	**0.90**	−0.21	0.55	**0.97**	**0.84**	0.66	0.30	1			
SO$_4$	−0.16	0.15	0.15	−0.16	0.05	0.04	0.19	0.16	−0.10	0.15	1		
NO$_3$	−0.47	**0.90**	**0.90**	−0.19	0.52	**0.95**	**0.84**	0.59	0.32	**0.93**	−0.15	1	
F	−0.49	**0.80**	**0.80**	−0.07	0.54	**0.83**	**0.83**	0.61	0.34	**0.81**	0.15	**0.85**	1

[#]Bold letters depict the strong correlation between the parameters
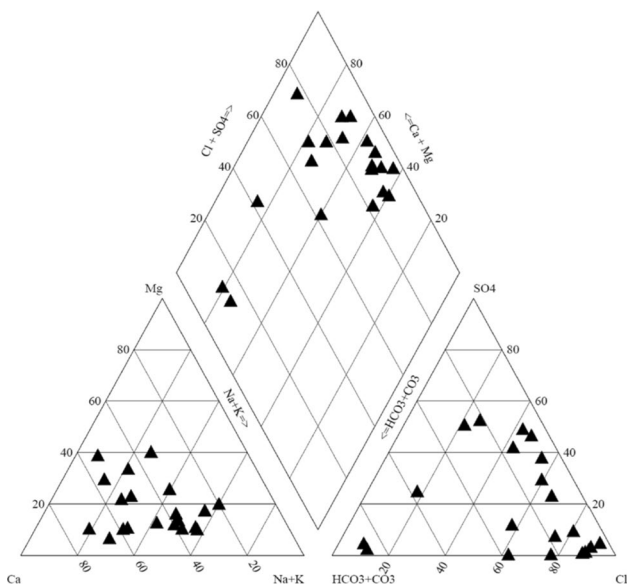
Fig. 6 Piper diagram for the representation of hydrochemical facies of the groundwater—Pre-monsoon
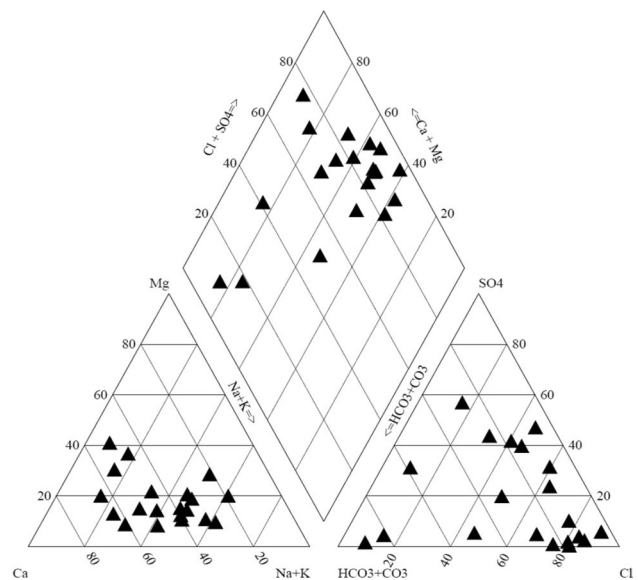
Fig. 7 Piper diagram for the representation of hydrochemical facies of the groundwater—Post-monsoon

3.3.2 Chemical nature of the groundwater

Piper trilinear diagram is a very convenient method to classify the groundwater [37]. This diagram is developed for the groundwater of Shillong for both pre-monsoon (Fig. 6) and post-monsoon (Fig. 7) seasons. It can be seen that during pre-monsoon season, most of the cations are calcium type and sodium and potassium type. Majority of the anions are chloride type, and a few are bicarbonate type. Similarly, in the post-monsoon season too, most of the cations are calcium type and majority of the anions are chloride type, and a few are bicarbonate type. Thus, seasonal variation does not have much effect on groundwater quality. Overall, groundwater samples are distributed among the calcium chloride and mixed-type hydrochemical facies.
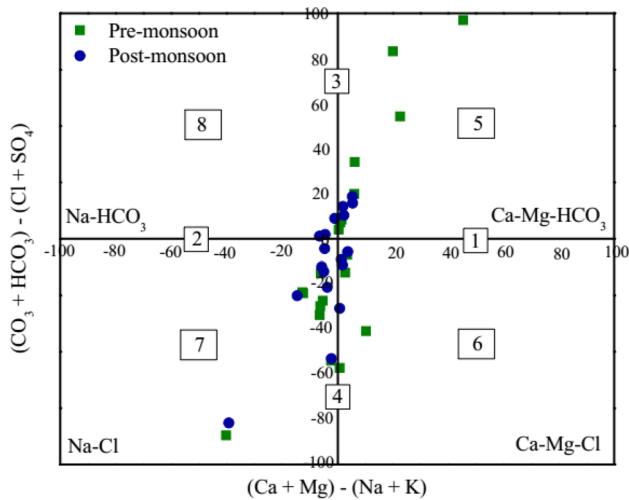
Fig. 8 Chadha's diagram for the representation of hydrochemical facies of the groundwater. (1. Alkaline earths exceed alkali metals, 2. alkali metals exceed alkaline earths, 3. weak acidic anions exceed strong acidic anions, 4. strong acidic anions exceed weak acidic anions, 5. Ca-Mg-HCO$_3$ type, 6. Ca–Mg–Cl type, 7. Na-Cl type, 8. Na-HCO$_3$ type)

The findings of Piper diagram can also be corroborated with the Chadha's diagram, as shown in Fig. 8. It can be seen that pre-monsoon samples are distributed among the three hydrochemical facies, viz. Ca-Mg-HCO$_3$ type, Na-Cl type, and Ca–Mg–Cl type. However, the post-monsoon samples are more or less equally distributed among the four facies, viz. Ca-Mg-HCO$_3$, Na-Cl, Ca–Mg–Cl, and Na-HCO$_3$, and hence, such groundwater may be called as the mixed type.

3.3.3 Gibbs diagram and rock-water interaction

To understand the mechanism of factors governing groundwater chemistry of Shillong, it is necessary to understand the Gibbs diagram [38]. Gibbs diagrams have been plotted for both cations and anions during pre- and post-monsoon seasons, as shown in Fig. 9. It is quite evident that during pre-monsoon as well as post-monsoon seasons, the rock dominance and atmospheric precipitation are the two most important mechanisms which are affecting the ionic concentration in groundwater of Shillong [38]. It is known that the important

cations in groundwater are Na, K, and Ca, while anions are the Cl and SO$_4$. Therefore, the relation between these ions and TDS is reflecting that the water is in partial equilibrium with the rocky content of the region [38]. Moreover, as Meghalaya is one of the most heavily down poured regions of India, the dominance of atmospheric precipitation mechanism is very much obvious. It also indicates that the chemical constituents in the groundwater are influenced by the dissolved salts which are obtained from atmospheric precipitation.

These diagrams indicate that rock weathering in the region is not the major mechanism controlling the chemistry of the groundwater. Rather, the composition of dissolved salts is influenced by the atmospheric precipitation as well.

3.3.4 Mode of weathering and identification of hydrogeochemical processes

Gibbs diagram reflected that rock weathering is one of the factors responsible for controlling the groundwater chemistry apart from atmospheric precipitation. Therefore, it is important to explore the weathering process. Scatter diagram of (Ca + Mg) *vs.* (HCO$_3$ + SO$_4$) in Fig. 10a shows that the samples lie near the equiline in carbonate weathering zone both during the pre-monsoon and post-monsoon seasons. It shows that carbonate weathering is the predominant mechanism affecting the Shillong's groundwater. To determine the rock types of Ca and Mg involved in the weathering process, ratio of Ca/Mg is calculated. Ca/Mg ratio of unity denotes the dissolution of dolomite rocks, while higher ratios indicate the dominance of calcite rocks [4, 39]. Further higher ratios of Ca/Mg, viz. Ca/Mg > 2, represent the dissolution of silicate minerals in the groundwater [40]. The Ca/Mg ratio in groundwater of Shillong district shows the weathering of silicate minerals in the rocks as both the pre-monsoon and post-monsoon samples lie above the Ca/Mg ratio of 2.

4 Conclusion

The study was carried out to assess the suitability of groundwater of Shillong region in India for drinking and irrigation purposes and to understand various hydrochemical processes involved. It was found that groundwater in the region is acidic in nature along with having
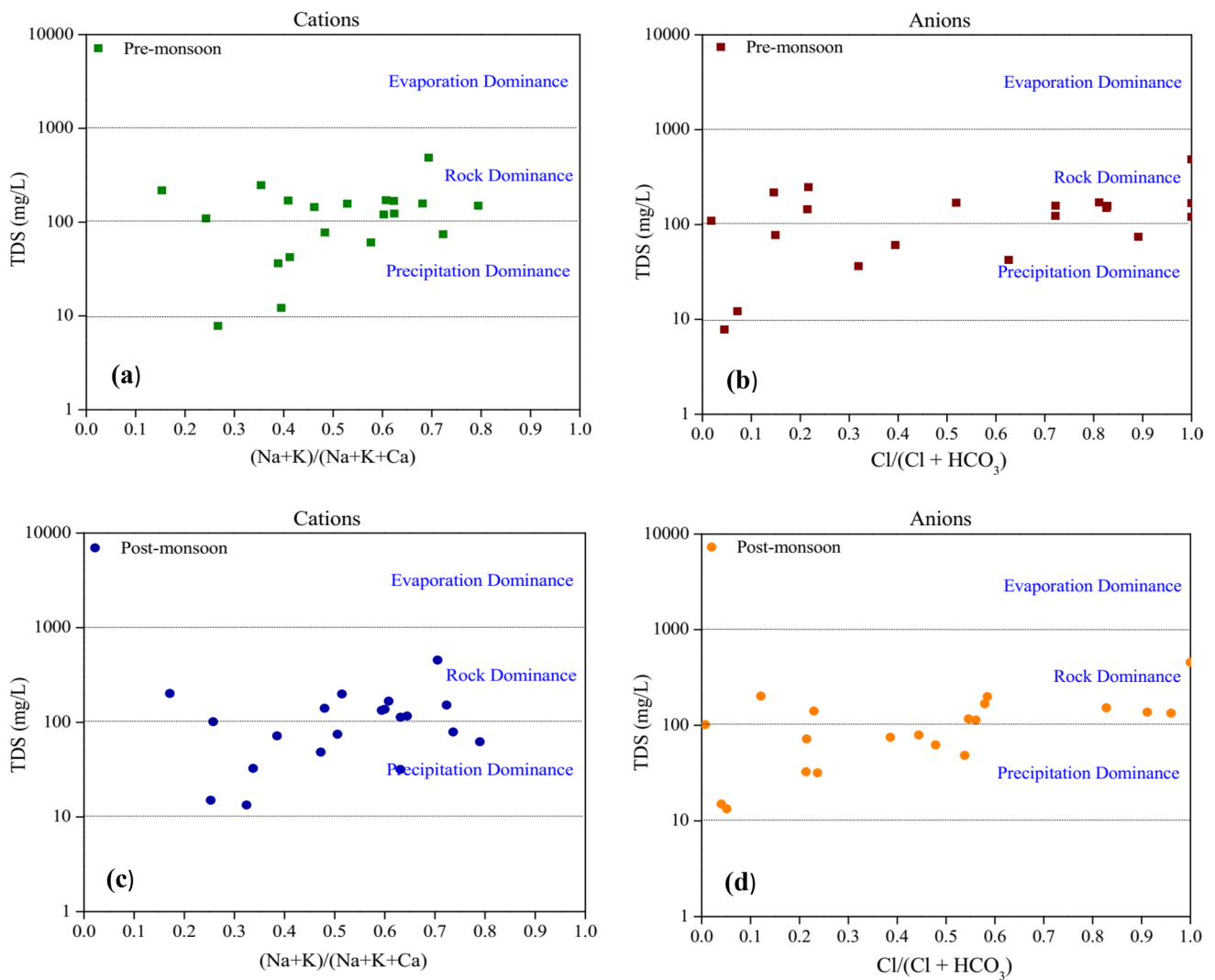
Fig. 9 a–d Gibbs plots, depicting the mechanisms controlling groundwater chemistry in Shillong

high concentration of nitrate. Iron and manganese were also found in high amount. Among the metals, nickel, mercury, and cadmium were in high concentration in some of the samples which is an issue of concern. Anthropogenic factors could be attributed to the high concentration of these parameters. Consumption of water contaminated with such metals might result in variety of health ailments, and therefore, its utilization for drinking without necessary treatment is not recommended. However, adoption of suitable removal technologies, such as oxidation/filtration,

might help in improving the water quality. Moreover, the water quality in the region was found suitable for agricultural purposes in respect of all the parameters except magnesium ratio and corrosivity ratio. The variation in the groundwater samples of pre-monsoon and post-monsoon seasons was found minimal. Hydrochemical studies inferred that the groundwater in the region is influenced by the rock weathering along with the atmospheric precipitation considering that Meghalaya is the highest down poured state in India.
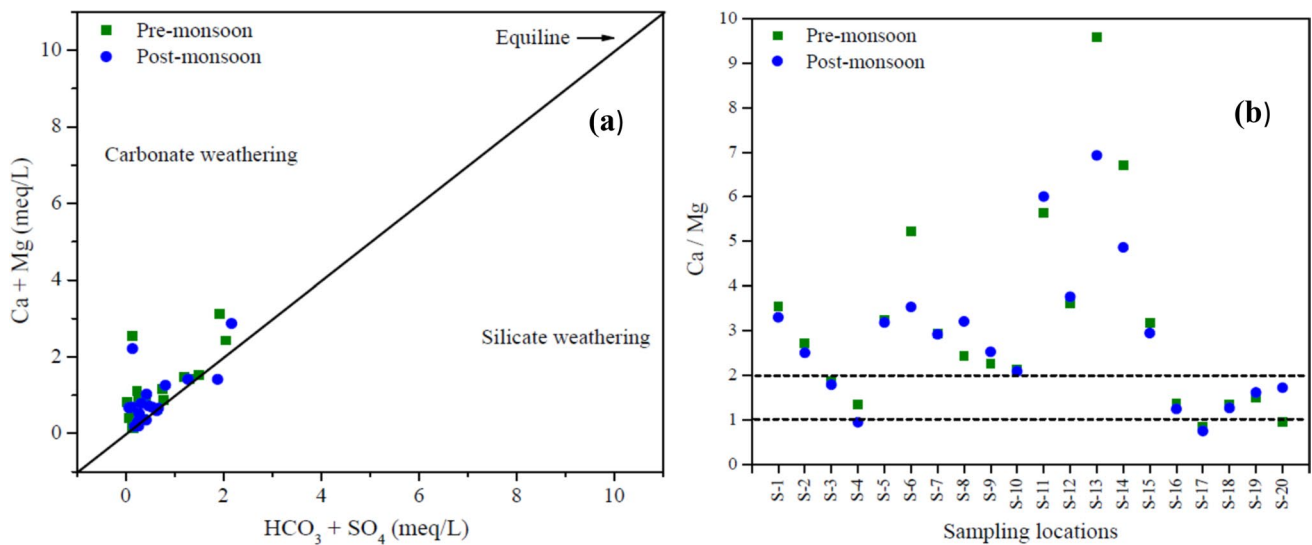
Fig. 10 **a**–**b** Mode of weathering in groundwater of Shillong representing that carbonate weathering is the predominant mechanism

Compliance with ethical standards

Conflict of interest Authors declare no conflicts of interest.

Ethical approval Not applicable.

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