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Groundwater Suitability for Irrigation and Livestock Consumption in the Chittagong University Campus, Bangladesh: A Hydro-geochemical and Multivariate Analysis

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Abstract

The present study aimed to assess groundwater quality of the Chittagong University Campus (CUC) in Bangladesh for irrigation and livestock consumption. Water samples were collected from irrigation pump stations during summer (June-July, 2019) and winter (December, 2019-January, 2020). Agricultural quality parameters like SAR, SSP, RSBC, and PS satisfied the analyzed water's irrigation suitability. However, according to MAR parameters, 37.5% of water samples were unsuitable for irrigation in both seasons. And, based on KR parameters, 12.5% of samples collected in the summer season only were unsuitable for irrigation. The Wilcox diagram showed that 100% of water samples are suitable for irrigation, while Doneen graph suggested that 87.5% of water is unsuitable. The mean trend of cations and anions was Na^+>Ca^{2+}>Mg^{2+}>K^+ and HCO_3^->Cl^->NO_3^->SO_4^{2-}>PO_4^{3-} respectively. The Piper and Chadha diagrams indicated Ca^{2+}-Mg^{2+}-HCO_3^- type water in both seasons. Gibbs plot ensured mostly the rock dominance zone. The ion ratio graphs revealed that the weathering of silicates and carbonates dominated the area's hydrochemistry. The Mg/Ca and Na/Ca plot declared no infiltration problem of minerals from water to soil. According to the Soltan classification, waters were classified as Na^+-HCO_3^- and shallow meteoric type. These water quality parameters fell within the acceptable range of livestock consumption. The principal component analysis (PCA) of these parameters indicated the introduction of geogenic and anthropogenic pollutions. The irrigation water quality index (IWQI) analysis of samples resulted in excellent to good water quality during both seasons. This study demonstrated that the water quality of CUC is acceptable for irrigation and livestock consumption.

1. Introduction

Groundwater is regarded as one of the most vital source of water for domestic, industrial, and agricultural purposes [1-3]. Agriculture plays a dominant role in the development of economy of Bangladesh [4]. About 70% of the total land relies on groundwater for irrigation in Bangladesh [5]. Therefore, irrigation water quality needs continuous monitoring in order to achieve sustainable development [6]. No doubt, Bangladesh is experiencing hasty urbanization in recent decades, and it is undeniably related to the aggravation of groundwater quality in terms of crucial quality parameters e.g., pH, electrical conductivity (EC), total hardness (TH), salinity, total dissolved solids (TDS), ions, and trace metals in different regions of Bangladesh [7]. On the other hand, water levels are declining due to open channel irrigation in different regions of Bangladesh [8]. Besides, salinity, sodium hazard, and excessive concentration of elements that may cause an ionic imbalance in plants are the primary concern for agriculture in Bangladesh [9].

To address the irrigation water quality, other than the parameters mentioned above, sodium adsorption ratio (SAR), soluble sodium percentage (Na%), magnesium adsorption ratio (MAR), permeability index (PI), residual sodium bicarbonate (RSBC), Kelley's ratio (KR), and potential salinity (PS) are the most critical factors to be monitored [10]. In addition, study of hydro-geochemical characteristics is necessary for effective utilization of groundwater with the accurate prediction of geochemical changes [11]. Multivariate analysis like principal component analysis (PCA), Piper diagram, Chadha, and Gibb's plot are useful tools to understand the hydro-geochemical processes identifying the pollution sources [12-14]. Furthermore, irrigation water quality index (IWQI) helps to express water quality in numerical terms [15, 16]. The IWQI model is to be used for irrigation quality assessment using EC, Mg^{2+}, Na^{+}, K^{+}, Cl^{-} and HCO_3^{-} parameters, which reflects soil salinity hazards with pollution level [17].

Due to the seawater intrusion, high salinity is affecting irrigation and livestock in the coastal region of Bangladesh [18]. Industrialization is a must for the development of any country; however, the big concern is its impact on groundwater quality as both are strongly related. Generally, agriculture using excess fertilizer, over-extraction, urban development, misleading irrigation practice, waste-water disposal, pit-latrines, dense population, animal waste, sewerage, as well as the physical composition of trace metals accumulation, weathering, dissolution, precipitation, ion exchange, and microbes are responsible for deteriorating groundwater quality. Therefore, continuous monitoring and appraisal of groundwater pollution in every potential area of an agricultural country is obligatory. Previously, scientists have revealed irrigation water quality and hydro-geochemical characterization of groundwater in Bangladesh [2, 5, 18-23]. Besides, water quality for livestock consumption has also been given equal importance. However, further investigation of groundwater quality for irrigation and livestock consumption in other areas of Bangladesh is warranted.

The University of Chittagong (CU) is one of the largest campuses in Bangladesh. It is a hilly landmass area, where groundwater is used for irrigation as the alternative source other than surface water. Most areas other than the campus building and playgrounds of the campus are used for agricultural activities. We selected the University campus as our study area because of the following reasons: (i) wider variation of people are living and working here due to the major infrastructure development, (ii) 0.17 kg per person per day is the waste generation rate in the campus, and the total solid waste of 1509 kg per day is generated here [24], (iii) 64 unscientific dumping sites in different places of the campus might pose a tremendous threat to livelihoods [24], (iv) Chittagong is the coastal area of Bangladesh, and the University is about 21.0 km and 36.0 km away from the Bhatiari and Sitakundo coast, where the large ship breaking has been established, (v) small scale industries were also built near the campus area, (vi) chemical wastes and medical wastes from the University are also dumped in an unscientific way, and (vii) the usage of fertilizers or pesticides in campus areas for agricultural activities. Taken together, the present study is designed for investigating groundwater quality of the campus to determine the suitability to use in irrigation purpose and livestock consumption. To the best of our knowledge, this is the first report on the groundwater quality assessment in the campus area for irrigation purpose and livestock consumption.

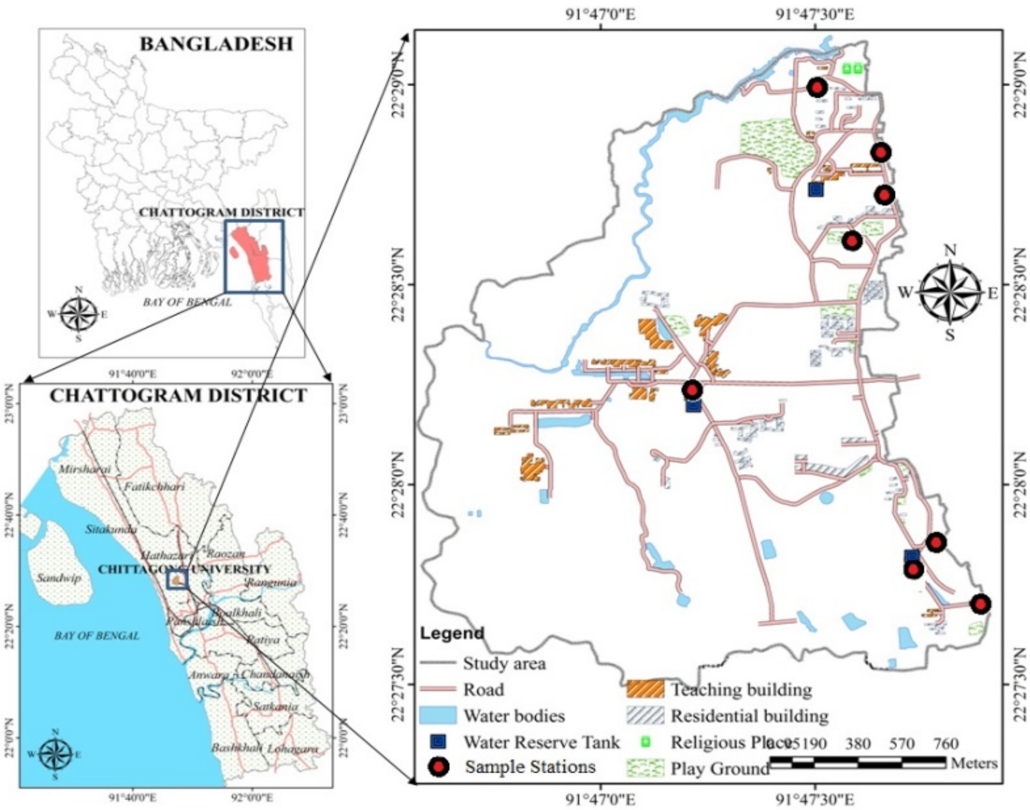

Figure 1: Study area of the CU campus.

2. Material and Methods

2.1. Study area

University of Chittagong (CU) is one of the largest (1754-acre) public universities in Bangladesh. The CU is 22 kilometers away (north side) from Chattagram city of Bangladesh, and situated in Jobra village of Fatehpur Union, Hathazari Upazila of Chattagram district. The study area extends from 91˚47′46.302″ to 91˚47′6.042″ E longitude and 22˚28′45.865″ to 22˚28′7.614″ N latitude. The average height of the aquifer is about 500 ft, which indicates the deep aquifer.

Table 1: Methods in brief

Parameters	Unit	Methods/Instruments
Temperature	ºC	Thermometer
pH	-	Combometer (Hanna portable combometer, Modelno:HI 9813-6)
Total Dissolved Substances (TDS) and Electrical Conductivity (EC)	mg/L and μS/cm	Combometer (Hanna portable combometer, Modelno:HI 9813-6)
Salinity	ppt	Hand Refractometer (Model no: REF201/211/201bp)
Total Hardness	mg/L	EDTA Titrimetric Method
Chloride	mg/L	Argentometric Method
Nitrate (NO_3^-), Sulfate (SO_4^{2-}), Phosphate (PO_4^{3-}) and Iron (Fe)	mg/L	Ultraviolet Spectrophotometer
Na, K, Ca and Mg	mg/L	Inductively Coupled Plasma Optical Emission Spectrometry
As	mg/L	Arsenic test kit (model- Merck 117917)

2.2. Sampling

Groundwater samples (sixteen, eight of each season) were collected from the pump stations (square-shaped blue; Figure 1) in summer (June-July, 2019) and winter (December, 2019-January, 2020) seasons. Sterilized (using nitric acid) plastic bottles were used for collecting water based on APHA (2017) method [25].

2.3. Analysis of physico-chemical parameters

Temperature, pH, electrical conductivity (EC), and total dissolved solids (TDS) were recorded at the pump stations during sampling procedure. Temperature was monitored by a thermometer. The pH, EC, and TDS were determined by a combometer, and salinity was checked by a hand refractometer (Table 1). The total hardness (TH) and chloride were determined through titrimetric method [25].The HCO_3^- was determined by titrating with HCl. The presence of nitrate (NO_3^-), Sulfate (SO_4^{2-}) and phosphate (PO_4^{3-}) were confirmed by UV-visible Spectrophotometer [25].

2.4. Trace metals assessment

Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES: Shimadzu 9820) was used to determine Na, K, Ca, and Mg at wavelengths of 588.983 nm, 7666.455 nm, 315.880, and Mg 279.071 nm, respectively, following the methodology developed previously [26]. Arsenic was determined by a test kit (Table 1). Iron was determined by UV-visible Spectrophotometer according to APHA (2017) method [25].

2.5. Statistical analysis

Statistical analysis was (mean, minimum, maximum, standard deviation, and PCA) performed by SPSS-16.0 software system. Piper diagram was plotted using grapher 9.0 software. Gibb's, Chadha, pie, and Wilcox diagrams, Donnen chart, Soltan classification, and ion ratio graph were plotted by MS-Excell 2016.

2.5.1. Irrigation water quality parameters

Irrigation water quality parameters were assessed by the equations presented in Table 2.

2.5.1. IWQI

IWQI was evaluated by a method explained by Meireles et al. (2010) [16]. Hence, EC, Na^+, Cl^-, HCO_3^-, and SAR were evaluated. Accumulation weight (W_i) based on their relative significance are presented in Table 3. Secondly, Q_i value was estimated by Ayers and Westcot (1994) [33] (Table 4). Q_i was calculated by the following equation (Eqn 8):

$$Q_i = q_{max} - \frac{(x_{ij} - x_{inf}) * q_{iamp}}{x_{amp}} \qquad (8)$$

Where, q_{max}= maximum value of q_i for each class; x_{ij} = observed/calculated value of each parameter; x_{inf} = corresponding value to the lower limit of the class to which the parameter belongs; q_{imp} = amplitude of each class; x_{amp} = class amplitude to which the parameter belongs. To evaluate x_{amp} of the last class of each parameter, the upper limit was considered to be the highest value determined in the physical-chemical analysis of the water samples. Finally, IWQI was calculated by the following equation (Eqn 9):

$$\mathrm{IWQI} = \sum_{i=1}^{n} \mathrm{Qi} * \mathrm{Wi} \quad (9)$$

where, i is the number of physico-chemical parameters.

Table 2: Equations to assess irrigation water quality parameters.

Parameters	Units	Eqn.	Eqn. No	Reference
SAR	meq/L	$\mathrm{SAR} = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+}+Mg^{2+}}{2}}}$	1	[27]
SSP or Na%	%	$\mathrm{SSP} = \frac{Na^{+} + K^{+}}{Na^{+} + Ca^{2+} + Mg^{2+}} \times 100$	2	[28]
KR	meq/L	$\mathrm{KR} = \frac{Na^{+}}{Ca^{2+} + Mg^{2+}}$	3	[29]
MAR	%	$\mathrm{MAR} = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} \times 100$	4	[30]
RSBC	meq/L	$\mathrm{RSBC} = HCO_3^{-} - Ca^{2+}$	5	[31]
PI	%	$\mathrm{PI} = \frac{Na^{+} + \sqrt{HCO_3^{-}}}{Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}}$	6	[32]
PS	meq/L	$\mathrm{PS} = Cl^{-} + \frac{SO_4^{2-}}{2}$	7	[32]

Table 3: Relative weight (W_i) of each parameter in IWQI

Parameters	W_i
EC	0.211
Na^{+}	0.204
HCO_3^{-}	0.202
Cl^{-}	0.194
SAR	0.189
Total	1.0

Table 4: Parameter limiting values for quality measurements (Q_i)

Q_i	EC	SAR $(meq/L)^{1/2}$	Na^{+} (meq/L)	Cl^{-} (meq/L)	HCO_3^{-} (meq/L)
85-100	200≤ EC <750	2≤ SAR <3	2≤ Na <3	1≤ Cl<4	1≤ HCO_3<1.5
60-85	750≤ EC <1500	3≤ SAR < 6	3≤ Na <6	4≤ Cl<7	1.5≤ HCO_3<4.5
35-60	1500≤ EC <3000	6≤ SAR <12	6≤ Na <9	7≤ Cl<10	4.5≤ HCO_3<8.5
0-35	EC <200 or EC ≥3000	SAR <2 or SAR ≥8.5	Na <2 or Na ≥9	Cl<1 or Cl ≥10	HCO_3<1 or HCO_3 ≥8.5

3. Results and discussion

3.1. General hydrochemistry

Hydrochemical studies in both seasons are presented in Table 5. The mean temperature values of the study area were 29.75±0.26 ºC and 24.36±0.87 ºC during summer and winter seasons, respectively, while the ranges were 29.40-30.10 ºC and 23.40-26.0 ºC. TDS ranges between 38.0 to 69.0 mg/L with the mean value of 45.81±9.75 mg/L in the summer season, and between 45.0 to 93.10 mg/L with the mean value of 58.18±17.60 mg/L in the winter season. According to WHO (2004) [34] classification, all the samples in this study area were excellent (Table 6). EC is mainly related to the salinity of groundwater [2]. EC value was 60.0±16.90 μS/cm (mean value) in the summer season, and 68.75±23.53 μS/cm (mean value) in the winter season, which classified as low saline water as per the guideline by WHO (2004) [34]. Salinity of 0 ppt was found in the present study. According to Wilcox (1955) [35] and Richards (1954) [27], water of this study area is classified as excellent (Table 7).

Table 5 : Descriptive statistics of physico-chemical and calculated parameters of groundwater at CU campus

Parameters	Summer (n=8)		Winter (n=8)	
	Range	Mean ± SD	Range	Mean ± SD
Temperature	29.40-30.10	29.75±0.26	23.40-26.0	24.36±0.87
TDS	38.0-69.0	45.81±9.75	46.30-93.10	58.18±17.60
EC	50.0-100.0	60.0±16.90	50.0-110.0	68.75±23.53
pH	5.90-6.80	6.49±0.29	5.70-6.90	6.33±0.42
Salinity	0.0	0.0	0.0	0.0
TH	14.0-44.0	21.50±10.40	14.0-42.0	22.0±9.07
Na^+	5.36-13.37	9.30±2.64	4.81-12.95	9.26±2.65
K^+	0.48-1.10	0.79±0.24	0.50-1.04	0.80±0.22
Ca^{2+}	3.80-8.16	6.41±1.78	3.20-8.45	6.12±1.94
Mg^{2+}	1.56-6.0	3.70±1.53	1.99-6.02	3.87±1.45
HCO_3^-	16.0-41.10	24.75±8.47	15.0-48.30	24.80±12.32
Cl^-	2.10-8.13	5.01±1.95	1.10-4.90	3.05±1.40
NO_3^-	0.0-1.80	0.96±0.71	0.03-1.70	0.97±0.68
SO_4^{2-}	0.02-.07	0.05±0.02	0.01-.07	0.04±0.02
PO_4^{3-}	0.01-.06	0.04±0.02	0.01-.08	0.04±0.02
Fe	0.85-1.47	1.21±0.18	0.82-1.72	1.18±0.27
As	ND	ND	ND	ND
SAR	0.42-0.89	0.73±0.17	0.38-0.88	0.73±0.16
SSP	29.31-52.18	40.95±8.23	27.69-48.33	40.76±7.38
RSBC	-0.09-0.27	0.09±0.11	-0.06-0.39	0.10±0.15
PI	79.29-128.90	100.56±15.30	83.99-113.62	98.82±9.38
MAR	37.75-60.92	47.97±8.22	44.69-65.94	50.93±7.18
KR	0.38-1.01	0.68±0.22	0.34-0.87	0.67±0.19
PS	0.06-0.23	0.14±0.06	0.03-0.14	0.09±0.04
Mg/Ca	0.61-1.56	0.97±0.33	0.81-1.94	1.09±0.38
Na/Ca	0.52-2.04	1.34±0.45	0.64-2.49	1.42±0.54
Ca/Mg	0.64-1.65	1.14±0.37	0.52-1.24	0.99±0.25
Mg/Na	0.20-0.61	0.40±0.14	0.52-1.35	0.82±0.27
Ca/Na	0.49-1.61	0.85±0.38	0.40-1.57	0.81±0.36
HCO_3/Na	0.65-1.91	1.04±0.39	0.58-1.63	1.02±0.36

The pH value was 6.49±0.29 in the summer, and 6.33±0.42 in the winter season. The slight acidic groundwater was due to the free CO_2 and HCO_3^- concentrations [36, 37]. TH is used to determine suitability of groundwater for various applications. The groundwater's TH value was 21.50±10.40mg/L in the summer season, and the value was 22.0±9.07 mg/L in the winter season. The water of this study area could be classified as soft water based on Sawyer and McCarthy (1967) [38] and Durfor and Becker (1964) [39] classification, the water in this area can be classified as soft (Table 8).

Table 6 : Groundwater classification based on TDS (WHO 2004) [34]

Category	Grade	% Summer	% Winter
Excellent	<300	100	100
Good	300-600		
Fair	600-900		
Poor	900-1200		
Unacceptable	>1200		

Table 7: Groundwater classification based on EC

Category	Grade	% Summer	% Winter
EC (Wilcox 1955) [35]			
Excellent	<250	100	100
Good	250-750		
Permissible	750-2250		
EC (Richards 1954) [27]			
Excellent	<250	100	100
Good	250-750		
Permissible	750-2250		
Unsuitable	> 2250		
EC (WHO 2004) [34]			
Low salinity	0-250	100	100
Medium salinity	250-750		
High salinity	751-2250		
Very high salinity	2251-6000		
Extensively high salinity	6001-10000		
Brine	>10000		

Table 8 : Groundwater classification based on TH

Category	Grade	% Summer	% Winter
TH (Sawyer and McCarthy 1967) [38]			
Soft	<75	100	100
Moderately hard	75-150		
Hard	150-300		
Very hard	>300		
TH (Durfor and Becker 1964) [39]			
Soft	0-60	100	100
Moderate	61-120		
Hard	121-180		
Very hard	>181		

The major abundant cations were Na^+, K^+, Ca^{2+}, and Mg^{2+} as determined by ICP-OES. Among these, Na^+ contributed with the highest concentrations in both seasons and constituted 46% of total cations in both seasons (Figure 2). Ca^{2+} and Mg^{2+} were found with less dominance than Na^{+} (Figure 2). K^{+} constituted the least concentrations (4%) during both seasons (Figure 2). The trend of significant cationic concentrations were $Na^{+}>Ca^{2+}>Mg^{2+}>K^{+}$. On the other hand, HCO_3^{-} was the highest dominant anion and constituted 80.33% and 85.81% of total anions in the summer and winter seasons, respectively (Figure 2).

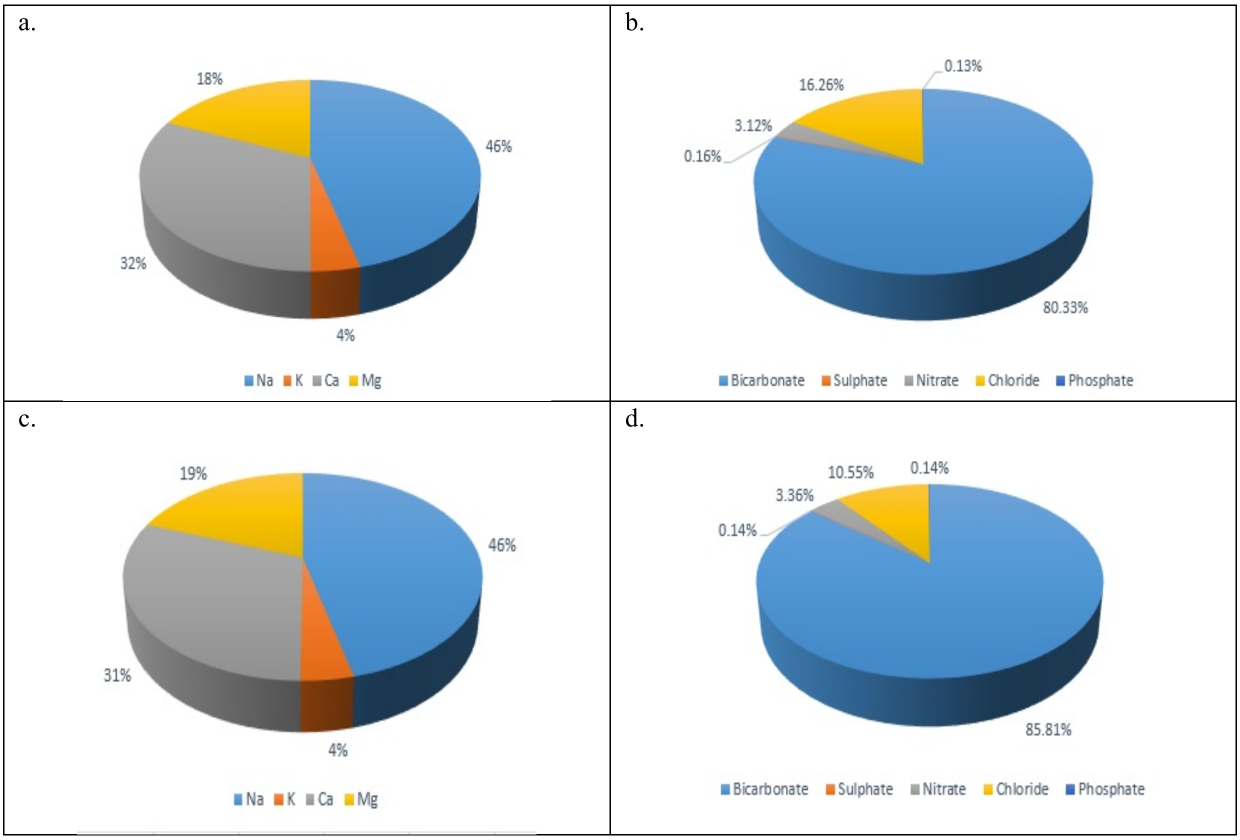

Figure 2 : Major ions in groundwater during summer (a,b) and winter (c,d).

Table 9 : Groundwater classification based on Chloride (Stuyfzand 1989) [41]

Category	Grade	% Summer	% Winter
Extremely fresh	<0.14		
Very fresh	0.14-0.84		
Fresh	0.84-4.23	37.5	75.0
Fresh-brackish	4.23-8.46	62.5	25.0
Brackish	8.46-28.21		
Brackish-salt	28.21-282.1		
Salt	282.1-564.3		
Hyperhaline	>564.3		

According to Mandel and Shiftan (1981) [40] classification, all the samples were in the safe category. Cl^{-} is the second dominant anion and constituted 16.26% and 10.55% in both seasons (Figure 2). 37.50% and 62.50% water were fresh and fresh-brackish in the summer season, while 75% and 25.0% water were fresh and fresh-brackish in winter as prescribed by Stuyfzand (1989) [41] (Table 9). NO_3^{-} constituted almost 3% of total anions, and remaining SO_4^{2-} and PO_4^{3-} concentrations were very low compared to other parameters (Figure 2). The anionic trends of groundwater were as $HCO_3^{-}>Cl^{-}>NO_3^{-}>SO_4^{2-}>PO_4^{3-}$. The contamination of groundwater by arsenic and iron in Bangladesh is high [7].

However, arsenic was not detected in both of the seasons in this study area. However, mean concentrations of Fe were 1.21±0.18 mg/L and 1.18±0.27 mg/L in the summer and winter seasons respectively which lies within the permissible limit for irrigation purposes (5.0 mg/L) [42].

3.2. Irrigation water quality parameter

3.2.1. Na %

Na % classifies the irrigation water based on the permeability of soil [43]. Excess Na^+ may hinder plant growth either by limiting the uptake of water or metabolic reactions [44]. According to Wilcox (1955) [35] classification, 37.50% and 50.0% of the study water samples fell in 'good category' and 62.50% and 50.0% in 'permissible category' during summer and winter seasons, respectively (Table 10). The Wilcox (1955) diagram classifies groundwater quality for irrigation plotting EC against Na%. It was observed that all the samples were classified as 'excellent to good' water quality for irrigation (Figure 3a). Moreover, as Eaton (1950) [45] approved, 100% of samples were safe for irrigation during both of the seasons (Table 10).

3.2.2. SAR

SAR was articulated by Richards (1954) [27] to evaluate Na^+ adsorption tendency on soil. Soil permeability is deteriorated with the increase of the concentration of Na^+ [46]. With the breaking down of the soil aggregates, the infiltration rate of water and air in soil is reduced [47]. All the water samples were in the 'no problem category' (Table 10) as settled by Bouwer (1978) [48] classification which conclude the suitability of irrigation water.

3.2.3. PI

Na^+, Mg^{2+}, Ca^{2+} and HCO_3^- content influence soil permeability which affects irrigation water quality [20]. According to Doneen (1962) [32] graph, the analyzed water was classified into three classes like class I (> 75% permeability), class II (25-75% permeability) and class Ш (25% of maximum permeability) type based on PI (Figure 3b). Water of class Ш is unsuitable for irrigation. In this study, 87.50% and 12.50% samples fell within class III and II respectively in both seasons. Therefore, based on Doneen plot (1962), the majority of samples are not suited for irrigations.

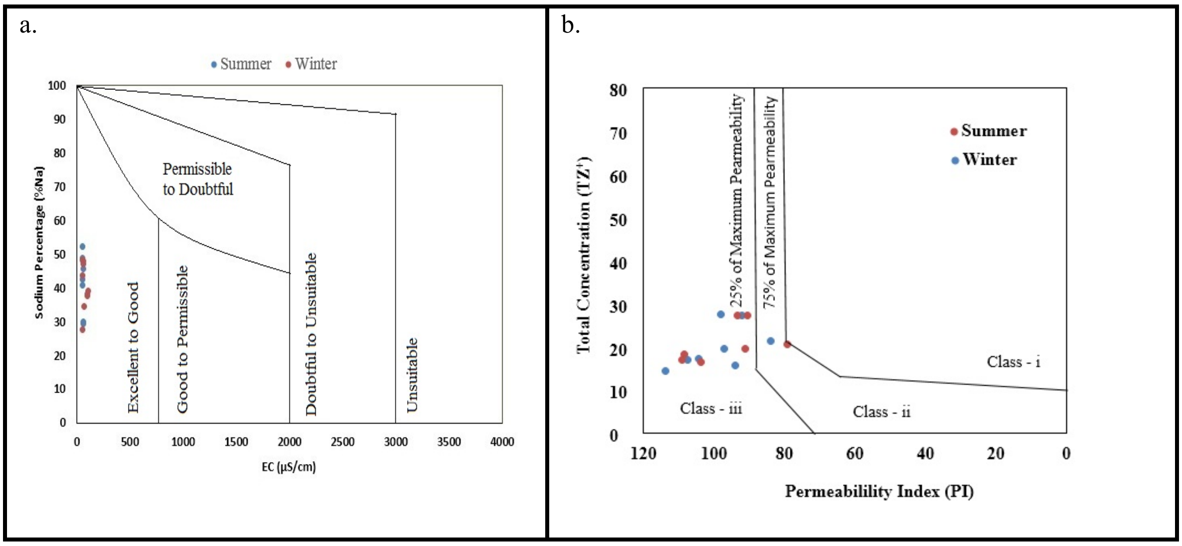

Figure 3:(a) Wilcox's diagram for irrigation water classification and (b) Doneen chart of water-based on the PI.

3.2.4. MAR

MAR defines the relationship between Na^+ and Mg^{2+} [49]. Excess Mg^{2+} causes infiltration problem [50]. If MAR is less than 50, it signifies suitability for irrigation where MAR value higher than 50 classifies water as unfavorable [51]. However, 62.50% of the samples were found suitable for irrigation during two different seasons (Table 10).

3.2.5. KR

Kelley's ratio rates the water quality with Na^+ measured against Ca^{2+} and Mg^{2+} [29]. According to this study, significant portions (87.50%) of the samples were 'suitable' (KR<1) and only 12.50% were 'unsuitable' for irrigation during summer (Table 10). On the other hand, 100.00% of samples were suitable for irrigation during winter.

Table 10 : Classification of groundwater quality for irrigation purpose

Category	Grade	% Summer	% Winter
Na % (Wilcox 1955) [35]			
Excellent	0-20		
Good	20-40	37.50	50.0
Permissible	40-60	62.50	50.0
Doubtful	60-80		
Unsuitable	>80		
Na % (Eaton 1950) [45]			
Safe	<60	100.0	100.0
Unsafe	>60		
SAR (Bouwer 1978) [48]			
No problem	<6	100.0	100.0
Increasing problem	6-9		
Severe problem	>9		
RSBC (Gupta and Gupta 1987) [31]			
Satisfactory	<5	100.0	100.0
Marginal	5-10		
Unsatisfactory	>10		
MAR (Kacmaz and Nakoman 2009) [51]			
Suitable	<50	62.50	62.50
Unsuitable	>50	37.50	37.50
KR (Kelley 1963) [29]			
Suitable	<1	87.50	100.0
Unsuitable	>1	12.50	
PS (Doneen 1962) [32]			
Suitable	<3	100.0	100.0
Unsuitable	>3		

3.2.6. RSBC and PS

RSBC and PS are important parameters to detect the suitability of irrigation water. According to Gupta and Gupta (1987) [31] and Doneen (1962) [32] classification, all samples fell in the 'satisfactory level' in both seasons, and suitable (<3 meq/L) for irrigation according to PS values (Table 10).

3.3. Hydro-geochemical classification

3.3.1. Piper diagram

The Piper (1944) [52] diagram is a handy tool to classify water based on hydro-geochemical characteristics establishing a relationship between dissolved constituents [53]. Two triangles on the left and right and a diamond shape diagram in the center show the classic piper trilinear diagram, indicating cations, anions, and combined dominance of cations and anions, respectively. The diamond shape diagram is divided into four major parts, where each part represents a particular type of compound. These parts are Na^+-K^+-HCO_3^- (category 1), Ca^{2+}-Mg^{2+}-HCO_3^- (category 2), Na^+-K^+-Cl^--SO_4^{2-}-NO_3^- (category 3), and Ca^{2+}-Mg^{2+}- Cl^--SO_4^{2-}-NO_3^- (category 4). All the samples fell in category 2, which indicates Ca^{2+}-Mg^{2+}-HCO_3^- water type for both seasons (Figure 4). This phenomenon suggests temporary hard water and could be certified by rock-water inter-relationship [54].

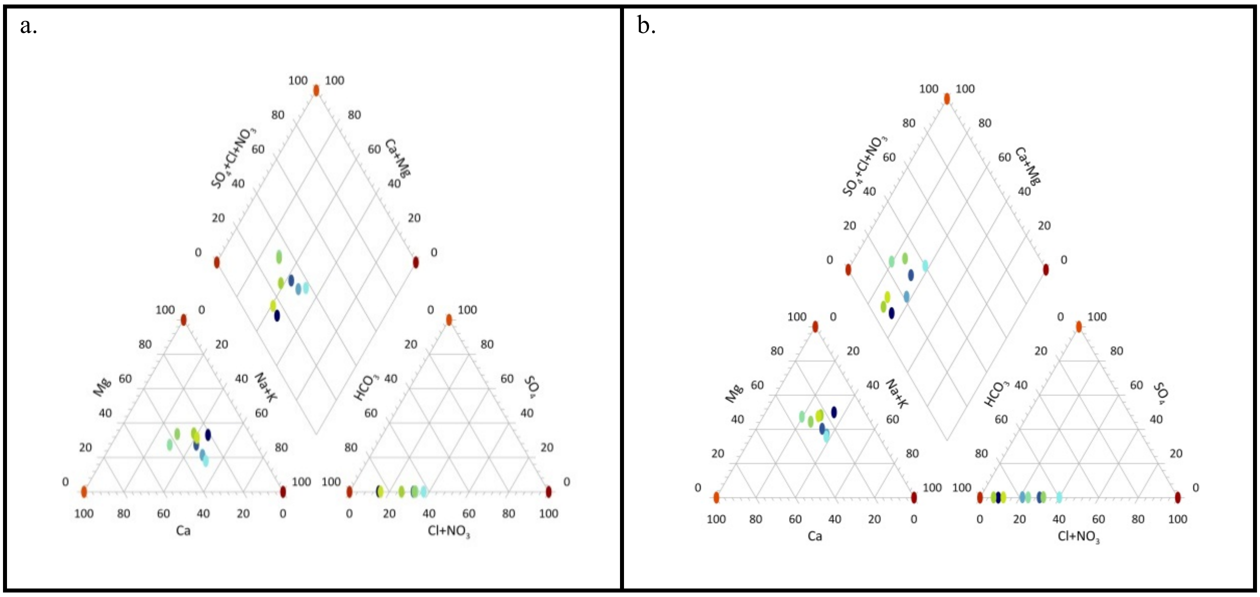

Figure 4: Chemical composition of groundwater during (a) summer and (b) winter seasons.

3.3.2.Chadha diagram

Chadha proposed a diagram to categorize the natural water according to hydrochemical analysis [55]. Ca^{2+}-Mg^{2+}-HCO_3^- type water was found from Chadha plot in both seasons except one sample in the summer season (Figure 6). Same type of water was also obtained from the Piper diagram (Figure 5).

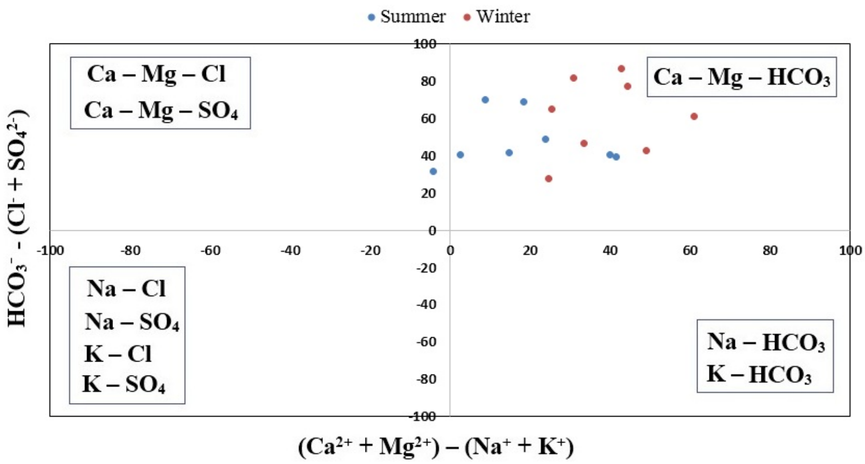

Figure 5: Chadha diagram demonstrating the hydrochemical classification of groundwater.

3.3.3. Gibbs Diagram

Gibbs (1970) [56] diagram establishes the relationship of water composition with lithological properties with the assessment of the sources of dissolved ions [4]. The Gibbs's graph indicates that most of the groundwater samples (100% and 81.25%) fell in the rock dominance zone in the summer and winter seasons (Figure 6), which might be controlled by the process of carbonate mineral dissolution and hydrolysis of silicate [57]. Noticeably, 18.75% of samples were found in the precipitation dominance zone in the winter season (Figure 6) which signifies that dissolved ions or salts control low-salinity waters [56].

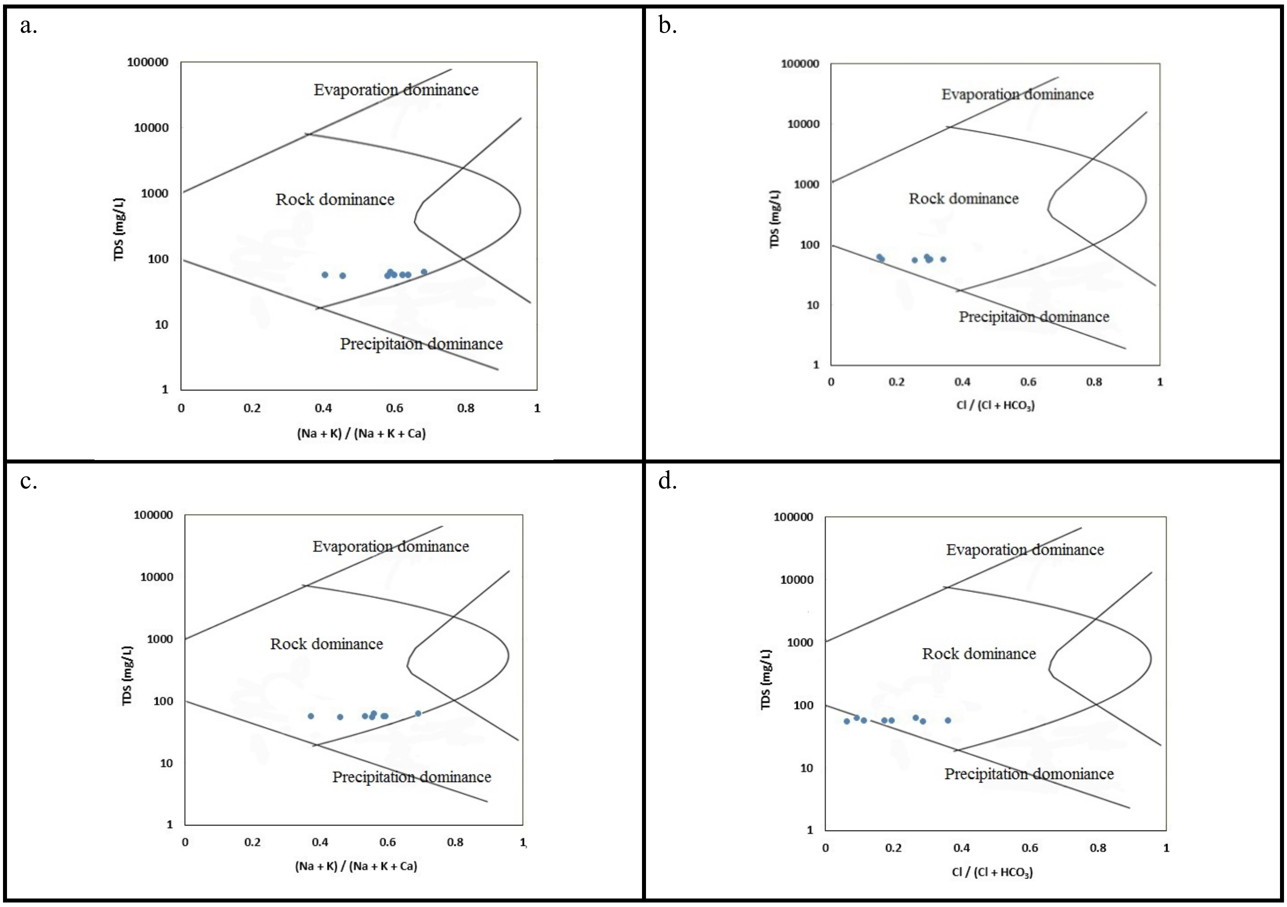

Figure 6 : Gibbs plot showing the mechanism governing groundwater chemistry during (a, b) summer and (c, d) winter seasons.

3.3.4. Ions ratio towards hydro-geochemistry

Ion ratio determines the rock weathering processes (silicate weathering, carbonate, and evaporate dissolution) that drives hydrochemistry [12]. The mean values of Mg/Na, Ca/Na, and HCO_3/Na were 0.40±0.14 and 0.82±0.27, 0.85±0.38 and 0.81±0.36, and 1.04±0.39 and 1.02±0.36 in summer and winter seasons respectively (Figure 7) that indicated the dissolution of silicates [58]. Moreover, the molar ratio of Ca/Mg < 2 indicates carbonate dissolution, whereas the ratio >2 suggests the dissolution of silicates [59]. Ranges of the Ca/Mg ratio were 0.64-1.65 and 0.52-1.24 in the summer and winter seasons, indicating the carbonate's dissolution. On the other hand, Mg/Ca ratio <4 and Na/Ca<3 shows no risk of infiltration problems that permit the suitability of water for irrigation [22]. Here, Mg/Ca ranged from 0.61-1.56 and 0.81-1.94 with the mean value of 0.97±0.33 and 1.09±0.38 during the summer and winter seasons respectively (Table 5). Furthermore, Na/Ca ranged from 0.52-2.04 and 0.64-2.49 in the summer and winter seasons with the mean value of 1.34±0.45 and 1.42±0.54 respectively (Table 5). These values indicated no risk of infiltration. The values of Mg/Ca ratio (Table 5) were also lied in safe (< 1.5) and moderately safe limit (1.5-3.0) [60]. Therefore, dissolution of silicate coupled with carbonates controls the hydrochemistry in this area.

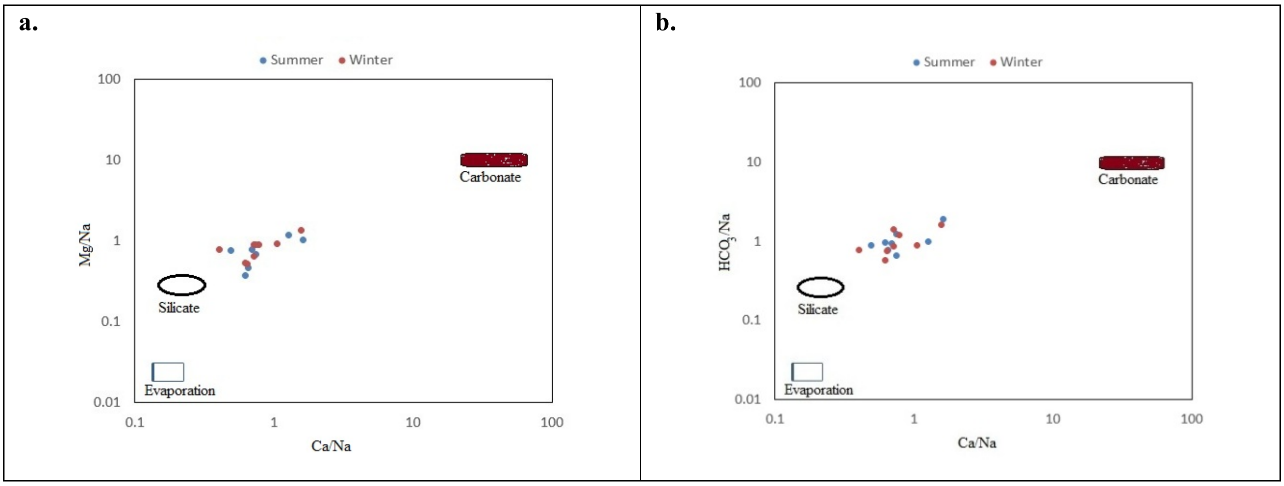

Figure 7: Diagrams of ionic ratio for groundwater samples

3.3.5. Soltan classification

According to Soltan (1998) [61] classification, groundwater are of two types, base-exchange indices ($r_1 = (Na^+ - Cl^-)/SO_4^{2-}$) and meteoric genesis indices ($r_2 = [(Na^+ + K^+) - Cl^-]/SO_4^{2-}$), where the unit of $r1$ and $r2$ are expressed as meq/L. $r1 < 1$ and $r2 < 1$ indicates Na^+–SO_4^{2-} and deep meteoric type source while $r1 > 1$ and $r2 > 1$ indicates Na^+-HCO_3^- and shallow meteoric type source. This study showed 100% of groundwater belonged to Na^+-HCO_3^- and shallow meteoric type (Figure 8 (a,b)).

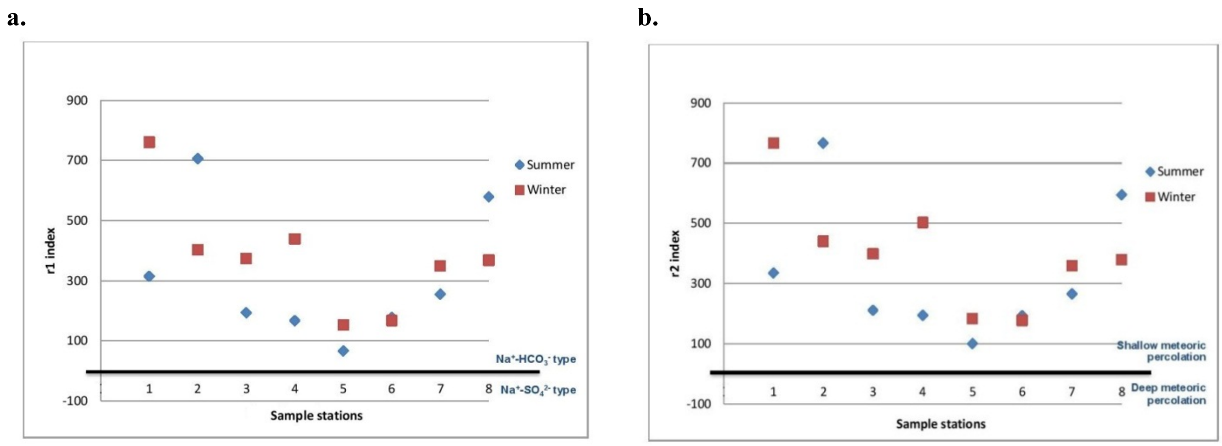

Figure 8: Soltan classification (a) base exchange index and (b) meteoric index genesis

3.3.6. Water quality for livestock consumption

Suitability of water for livestock can be evaluated by considering essential parameters like TDS, EC, pH, Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, NO_3^-, SO_4^{2-}, and other toxic elements [62, 63]. The safe level of different parameters is presented in Table 11, while the mean value of the parameters has shown earlier (Table 5). By comparing the mean values with standard values, water in this study area can be regarded as acceptable for livestock consumption.

Table 11: Safe levels of different parameters in water for livestock (Alassaf and Al-saffawi 2020) [62]

Parameters	Unit	Safe limits
TDS	mg/L	3000.0
EC	μS/cm	1600.0
pH	-	6.0-9.0
Na^+	mg/L	300.0
K^+	mg/L	20.0
Ca^{2+}	mg/L	1000.0
Mg^{2+}	mg/L	500.0
Cl^-	mg/L	300.0
SO_4^{2-}	mg/L	500.0
NO_3^-	mg/L	100.0
As	mg/L	0.2

3.4. Principal component analysis

PCA is normally used to determine some linear arrangements of variables by summarizing the data without losing significant data [64, 65]. The scree plot (Figure 9 (a, c)) and component plot (Figure 9 (b, d)) can be applied to identify the number of PCs and represent their values. Three PCs with eigenvalues >1 explaining the total variance of 79.759% and 87.267% were found during summer and winter seasons, respectively.

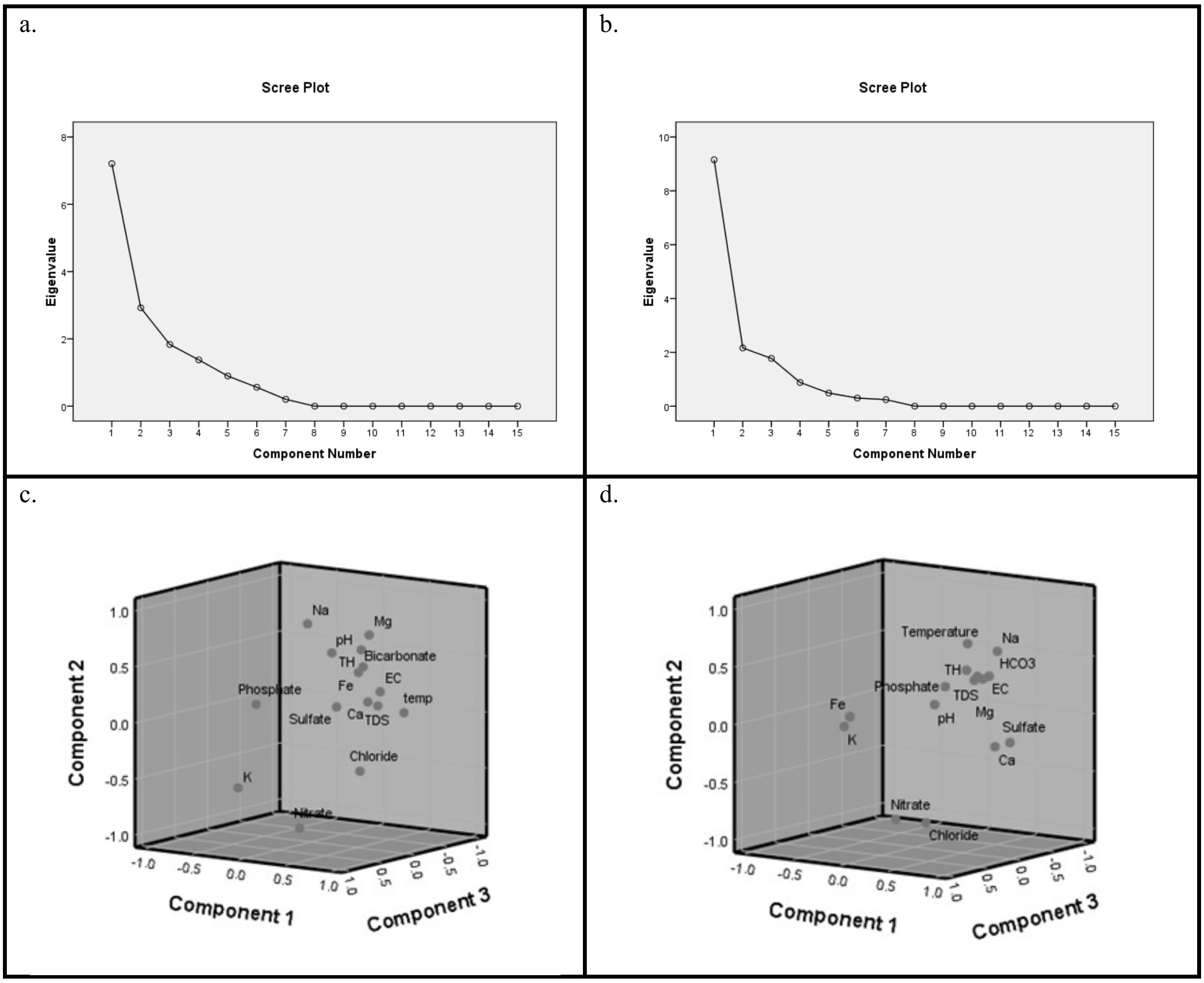

Figure 9: Scree plot with Eigenvalue of PCA and component plot in rotated space of PCA during (a, c) summer and (b, d) winter seasons.

PC1 (eigenvalues 7.208 and 9.154) explained 48.055% and 61.027% of the total variance during the summer and winter seasons, respectively. PC1 had strong to moderate positive loadings of temperature, TDS, EC, pH, TH, Cl^-, SO_4^{2-}, PO_4^{3-}, and HCO_3^- during both seasons and Ca in the winter season. It exhibited negative loading on NO_3^{2-} in both seasons, and K^+ in the winter season (Table 12). The reason could be due to the soil and groundwater interaction, anthropogenic pollution, and carbonate weathering [66, 67]. PC2 (eigenvalues 2.923 and 2.126) explained 19.488% of total variance during summer, and 14.415% during the winter season. Here, Na, K, and Mg dominated positively, and Fe dominated negatively in the summer season, whereas SO_4^{2-}, Na^+, and K^+ were dominated by positive loading in the winter season (Table 12). Finally, PC3 (eigenvalues 1.832 and 1.774) contributed 12.216% and 11.824% of the total variance in the summer and winter seasons. Mg^{2+} had positive loading in the winter season. Negative loadings of PC3 were found for Cl^- and Mg^{2+} during summer, and Fe in the winter season (Table 12). This variance could have resulted from the urban runoff, and organic and inorganic fertilizer incorporation [67, 68].

3.5. IWQI

The irrigation water quality index (IWQI) represents irrigation water quality in the numeric expression considering different significant parameters [69]. In this study area, all the sample stations fell in the 'good to excellent' category. 75.0% of samples fell in the 'excellent', and 25.0% of samples fell in the 'good' category during both seasons (Figure 10). According to IWQI, study water constituted a suitable category for irrigation. The present study with the findings is summarized in a flow chart (Figure 11).

Table 12: PCA of irrigation water quality parameters at CU campus

Parameters	Summer			Winter		
	PC1	PC2	PC3	PC1	PC2	PC3
Temp	**0.586**	0.117	0.479	**0.804**	-0.383	0.044
TDS	**0.832**	0.430	0.157	**0.946**	0.003	0.059
EC	**0.802**	0.223	0.161	**0.987**	-0.012	0.096
pH	**0.759**	-0.217	-0.117	**0.820**	0.265	-0.396
TH	**0.960**	0.063	-0.190	**0.946**	-0.052	-0.109
Chloride	**0.688**	-0.185	***-0.618***	**0.810**	-0.359	0.351
Nitrate	***-0.884***	0.371	-0.199	***-0.885***	-0.279	-0.087
Sulfate	**0.713**	0.007	0.382	**0.747**	**0.522**	0.259
Phosphate	**0.896**	-0.401	0.034	**0.981**	0.050	-0.064
HCO_3^-	**0.921**	0.102	-0.033	**0.968**	-0.007	-0.016
Na	0.439	**0.792**	0.357	-0.354	**0.779**	0.271
K	-0.498	**0.723**	0.399	***-0.685***	**0.624**	0.203
Ca	0.267	0.371	-0.220	**0.690**	0.425	0.470
Mg	0.317	**0.548**	***-0.670***	-0.236	-0.489	**0.551**
Fe	0.055	***-0.831***	0.387	0.224	0.210	***-0.866***
Eigen Value	7.208	2.923	1.832	9.154	2.162	1.774
% Total variance	48.055	19.488	12.216	61.027	14.415	11.824
Cumulative % variance	48.055	67.543	79.759	61.027	75.442	87.267

Bold figure denote significant '+' loading.
Bold and italic figure denote '-' loading.

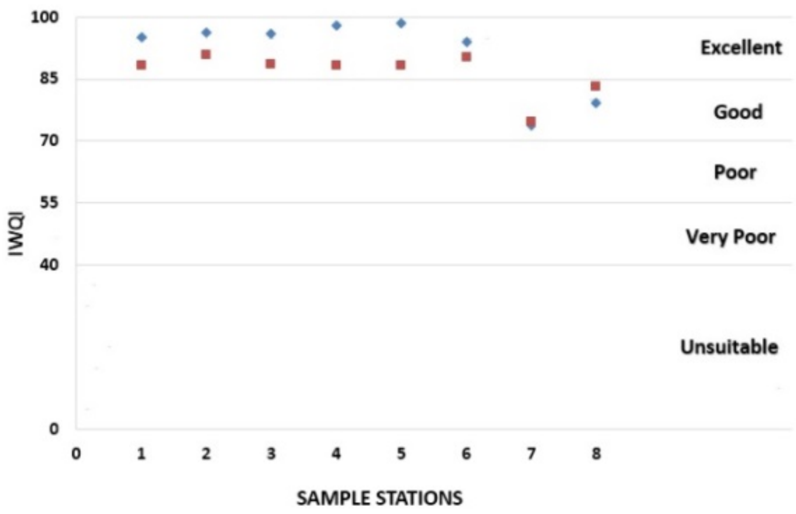

Figure 10: Groundwater classification based on IWQI.

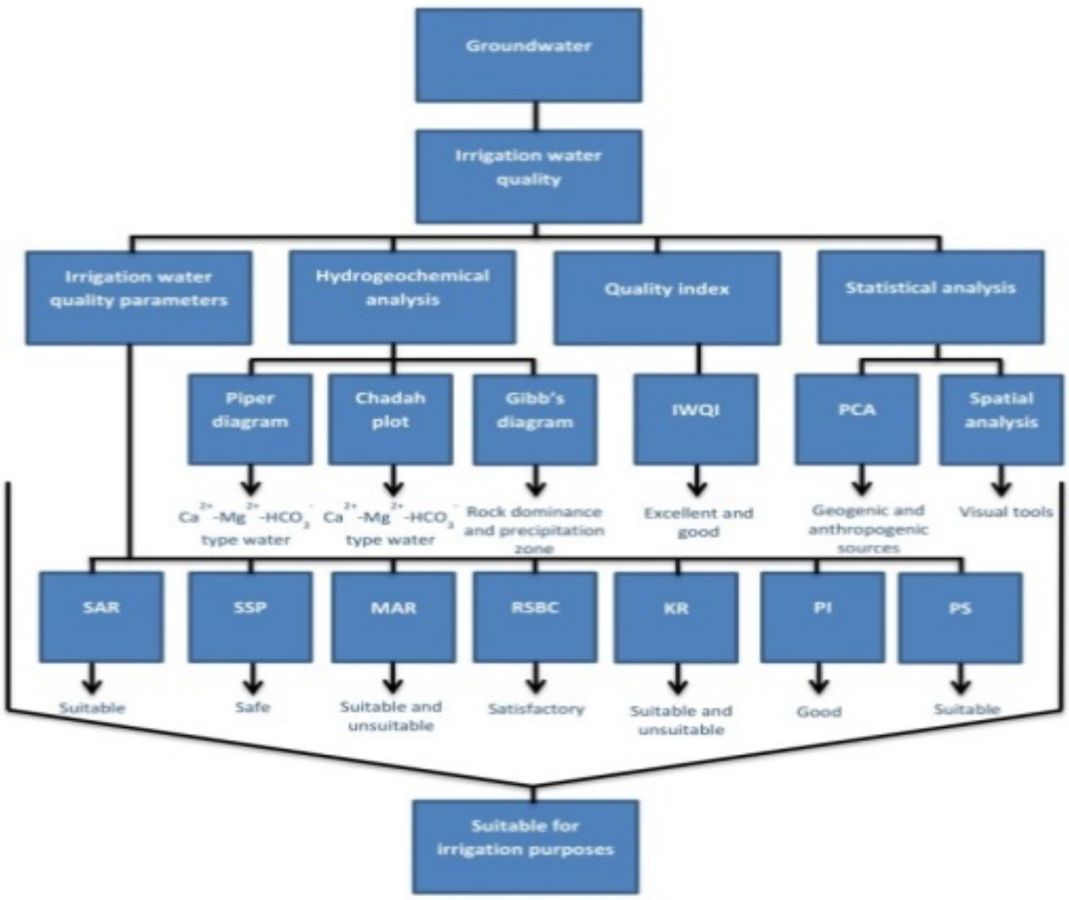

Figure 11: Flow chart of the present investigation.

Conclusion

Suitability of groundwater of Chittagong University Campus (CUC) for irrigation and livestock consumption with hydro-geochemical characterization was evaluated in the study. Except MAR, KR, and PI, other parameters certify the quality criterion for irrigation purposes. According to MAR, 37.5% of water samples in both seasons are unsuitable for irrigation, and according to KR, 12.5% of the summer season samples are unsuitable. Wilcox diagram ensured the suitability of water (100%) for irrigation, whereas the Donnen chart showed that 87.5% of water is unsuitable for irrigation. Hydrochemical analysis denoted the groundwater as fresh to fresh-brackish and soft. The trend of major ions is $Na^{+}>Ca^{2+}>Mg^{2+}>K^{+}$ and $HCO_3^{-}>Cl^{-}>NO_3^{-}>SO_4^{2-}>PO_4^{3-}$. The Ca^{2+}-Mg^{2+}-HCO_3^{-} type water is found according to Piper and Chadha diagrams. In addition, mostly rock dominance water was confirmed by the Gibbs diagram. The ion ratio graphs revealed the weathering of silicates and dissolution of carbonates dominated the hydrochemistry of water. No threat of Mg and Na's infiltration from water to soil was confirmed from Mg/Ca and Na/Ca ratio. Soltan classification showed Na^{+}-HCO_3^{-} and shallow meteoric type of water. These data demonstrated that water is suitable for livestock consumption. The geogenic and anthropogenic pollutions could be introduced in the groundwater, as suggested by the PCA data analysis. Excellent to good irrigation water qualities were confirmed by IWQI values during both summer and winter seasons. Therefore, we can conclude that CUC's groundwater is suitable for irrigation and livestock in summer and winter seasons.

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