Desalination and Water Treatment
www.deswater.com

doi: 10.1080/19443994.2016.1177598

57 (2016) 27614–27626
December

Taylor & Francis
Taylor & Francis Group

Assessment of hydrogeochemistry and water quality index (WQI) in some wetlands of the Brahmaputra valley, Assam, India

Sanghita Dutta, Rashmi Rekha Gogoi, Latu Khanikar, Rajat Shubro Bose, Kali Prasad Sarma*

Department of Environmental Science, Tezpur University, Napaam, Tezpur 784028, Assam, India, Tel. +91 8876396955; email: sanghitadutta1@gmail.com (S. Dutta), Tel. +91 8876160835; email: rrgogoi@tezu.ernet.in (R.R. Gogoi), Tel. +91 9954247375; email: latu@tezu.ernet.in (L. Khanikar), Tel. +91 8876450157; email: bose.rajat.bose@gmail.com (R.S. Bose), Tel. +91 9435180776; email: sarmakp@tezu.ernet.in (K.P. Sarma)

Received 11 January 2016; Accepted 6 April 2016

ABSTRACT

In the present study, geochemical characteristics of surface water have been studied considering seasonal variation. Water samples from 10 different wetlands of the Brahmaputra valley were collected and analyzed for pH, electrical conductivity, total dissolved solids, bicarbonate, chloride, sulfate, nitrate, calcium, magnesium, sodium, potassium and total hardness. The order of the abundance of the major cation and anion is as follows: $HCO_3^- > SO_4^{2-} > Cl^- > Na^+ > Ca^{2+} > K^+ > Mg^{2+} > NO_3^-$ in pre-monsoon and $HCO_3^- > SO_4^{2-} > Cl^- > Na^+ > Ca^{2+} > Mg^{2+} > K^+ > NO_3^-$ in post-monsoon. Both carbonate and silicate weathering occur in the wetlands although carbonate weathering was found to be dominant in post-monsoon. According to Gibbs diagram, the predominant samples fall in the rock–water interaction dominance. The Piper-trilinear diagram shows that the water samples belong to Ca^{2+}–Mg^{2+}–Cl^-–SO_4^{2-} type or facies in pre-monsoon, while in post-monsoon, most of the sample show temporary and permanent hardness due to Ca^{2+}–Mg^{2+}–HCO_3^-, and Ca^{2+}–Mg^{2+}–SO_4^{2-}, respectively, indicating a mixed type of water. Based on the water quality index, Deepor Beel and wetlands of Kaziranga National Park shows poor water quality. Principal component analysis used for source apportionment of the parameters indicated pH, HCO_3^-, TH, EC, TDS, Cl^-, Ca^{2+}, Mg^{2+}, Na^+, and K^+ as the mineral component of the wetlands, whereas Mg^{2+}, NO_3^-, and SO_4^{2-} originated from anthropogenic sources such as agricultural run-offs, nearby tea gardens and sewage sludge.

Keywords: Hydrogeochemistry; Water quality index; Principal component analysis; Physicochemical; Gibbs and piper diagram

1. Introduction

Wetlands are landscapes, either temporarily or permanently covered with water and exhibits enormous diversity according to their geographical location, genesis, water regime, and chemistry. Assam is endowed with many natural lentic water bodies locally known as beel [1]. Assam has 3,513 wetlands covering a total area of 1,012.32 ha. It constitutes 1.29% of the total geographical area of the state. This includes the natural and artificial wetlands, rivers,

*Corresponding author.

lakes, and agricultural fields. Of these, 3,388 wetlands are natural and dominate the state. Assam occupies seventh place according to geographic area under the wetlands of the country [2]. The Brahmaputra valley is situated between the hill ranges of the eastern and north-eastern Himalayan range. In Assam, the entire valley stretches from the western Brahmaputra valley covering the regions of Goalpara and Kamrup; the central Brahmaputra valley region covering Darrang, Nagaon, and Sonitpur districts; and the eastern Brahmaputra valley covering the districts of Lakhimpur, Dibrugarh, and Sibsagar with an entire stretch of 914 km^2. Wetlands in Assam are one of the most productive ecosystems of the region and plays an important role in the hydrological cycle. The wetlands studied in the work are situated in the floodplain areas of the Brahmaputra and are directly or indirectly linked with the major river system and its tributaries. Besides, it also has a link with the groundwater aquifers. The interaction between the groundwater and the surface water greatly influences the composition of the water through rock–water interaction and weathering of rocks. There is a wide spectral variation of meteorological, topographical, geomorphological, hydrological, geological, and hydrogeological conditions in the state. The chemistry of surface water is an important factor determining its use for domestic, irrigation and industrial purposes. The conventional techniques such as Piper trilinear diagram, Gibbs plot and scatter diagrams are widely accepted methods to determine the hydrogeochemistry of the water. The quality of surface water within a region is governed by both natural processes (such as precipitation rate, weathering processes and soil erosion, hydrological processes; physical, chemical and biological processes) [3,4] and anthropogenic effects (such as urban, industrial and agricultural activities and the human exploitation of water resources) [5,6]. The behavior of the pollutants in the water column varies according to the type of pollutant, water chemistry, reactivity of bedrock, geology of the catchment area, and amount of rain [7]. Accurate and timely information on the quality of water is indispensable to shape a sound public policy and to implement the water quality improvement programs efficiently [8,9]. It is interesting to note that most of the wetlands of Assam are Ecotones, which borrows species from both upland terrestrial forests and deep water river systems. This fragile ecosystem of the wetlands of Assam with diverse attributes serve as critical breeding, staging, and wintering grounds for wide areas of globally important bird species and some of them have been declared as Important Bird Area (IBA) by Birdlife International. Some of the important wetlands of the Brahmaputra valley are the Deepor beel (DB), which is the lone Ramsar site of the state of Assam and is representative of the wetland found within the Burma monsoon forest biogeographic region. It is one of the largest and most important riverine wetland and is polluting very rapidly. Several studies on the water quality of the DB have been done by [10–13]. Kaziranga national park (KNP) is a World Heritage site of the Brahmaputra valley. The wetland here plays a very significant role for its wildlife, but negligible work has been done to study its water quality. Although it is a protected area, it is vulnerable to the high traffic from the nearby highway NH-37; surrounding tea gardens and a high rate of increasing encroachment. Different other wetlands from the state have been studied for its limnology and aquatic life by [14–17]. But there has been no study till date to understand the geochemistry behind these wetlands and the water quality of the wetlands with regard to a pollution index to compare the status of the pollution occurring in the wetlands.

The main objective of the work was therefore to define the quality of water in the wetlands of the Brahmaputra valley with special reference to their physicochemical properties by calculating their water quality index (WQI). In order to have a better understanding, a detailed hydrogeochemical investigation of the wetlands has also been carried out to determine the major ion chemistry and their sources and to understand the role of weathering and other geochemical processes (precipitation and dissolution of minerals/salts, redox processes, etc.) in controlling the water composition of the wetlands in the Brahmaputra valley.

2. Materials and methods

2.1. Description of the study area

The Brahmaputra valley of Assam is made up of older and newer alluvium formed during the Pleistocene age. The older alluvium are generally found in slightly undulating areas in both sides of the Brahmaputra and the new alluvium soils near the river, built up of alluvial materials washed down from the hill. Assam has a Tropical Monsoon Rainforest climate with an average rainfall of around 1,500 mm per year. During summer, maximum temperature reaches at 95–100˚F or 35–38˚C and in winter, minimum at 43–46˚F or 6–8˚C and experiences heavy rainfall and high humidity.

The following wetlands from different districts of Assam were selected for the study (Fig. 1). The coordinates of the sampling locations are given in Table 1.

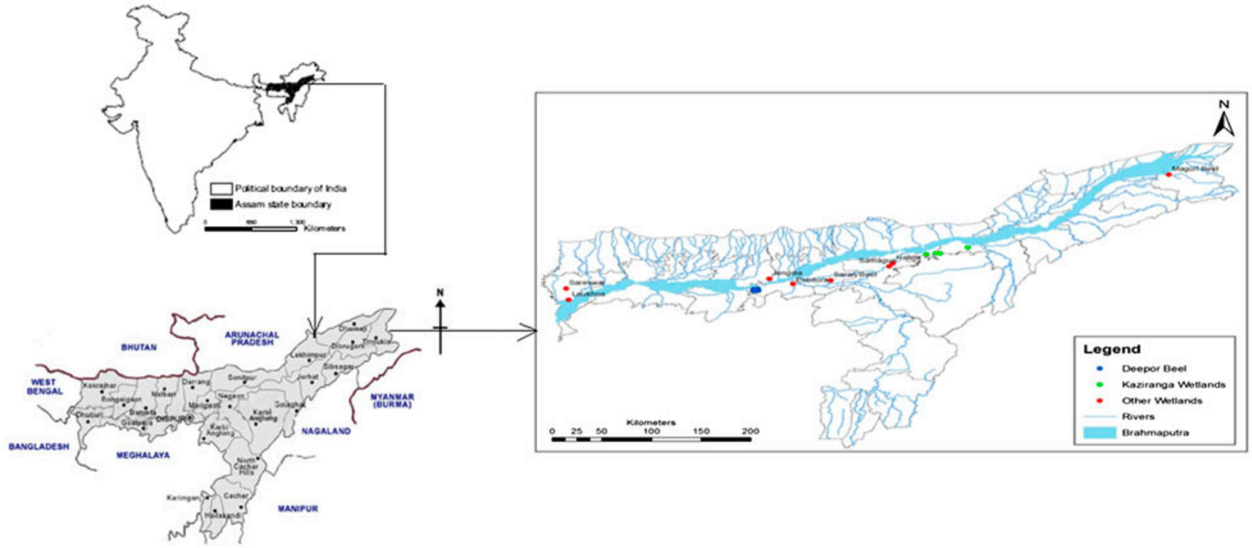

Fig. 1. Map showing the sampling sites.
Source: Map data ©2014 Google (India map); NAMP CENSUS, 2007 (Assam map).

2.1.1. Deepor beel (DB)

DB, located in the Kamrup District of Assam is one of the 21 national wetlands of India. It is a natural and permanent freshwater lake in a former channel of the Brahmaputra, located to the south of the present main river channel. It occupies a total area of 4,014 km^2. It is oriented to the southwest of the Guwahati city as a major storm water storage basin. DB is of International importance since it is a Ramsar site and an Important bird area (IBA), as declared by Birdlife International.

2.1.2. Wetlands of kaziranga national park (KNPw)

KNP is one of the most important protected areas in Assam, spread over an area of 429.93 km^2. KNP is situated in the flood plains of the Brahmaputra river and the entire area has been formed by silt deposition, carried by the different river systems flowing through it.

2.1.3. Maguri beel

It is situated near the Dibru Saikhowa National Park, which is 30 km from Tinsukia town. Here, two rivers, Dibru and Lohit flows along together and meets the Brahmaputra. To its south, exists a vast expanse of swamps and marshes interspersed with sandy islands. The beel is surrounded by tea gardens.

2.1.4. Samaguri beel

Samaguri beel is an Ox-bow lake created by the abandoned path of the Kolong river during the course of time. This lake is located about 16 km to the east of Nagaon town of Assam. It is famous as a Bird Pilgrimage site. The lake covers 0.613 km^2 land having average depth 8–10 m according to Assam Fishery Development Corporation.

2.1.5. Saran beel

Saran beel is located 4 km from Morigaon town. It is crecent shaped. The main source of water to the beel is the Kolong. To the west of the beel are agricultural fields and to the east is the Morigaon-jagiroad road. Nearby areas are quite densely populated. It is a perennial wetland and is a home to several migratory and local birds during winter.

2.1.6. Pobitora

It is situated 50 km from Guwahati city and is situated in the floodplain area of the Brahmaputra. The sanctuary has an area of about 38.81 km^2. Out of 38.81 km^2, 14.66% is wetlands. River Brahmaputra forms the northern boundary of the sanctuary (north of Mayang Hills), Revenue Villages numbering 37 lies along the east, south, and western boundaries.

2.1.7. Sareswar

Sareswar beel is a shallow, freshwater lake with abundant aquatic vegetation on the floodplain to the north of the Brahmaputra River in Dhubri districtwith a total area of 1,700 ha. The western edge of the

Table 1
Coordinates of the sampling locations

Sl. no.	Wetland	District	Latitude	Longitude
1	Deepor beel	Kamrup	26°11′N	91°35′E
2	KNPw	Golaghat and Nagaon	26°46′N	93°08′E
3	Maguri	Dibrugarh	27°47′N	95°28′E
4	Saran	Morigaon	26°14′N	92°19′E
5	Samaguri	Nagaon	26°25′N	92°51′E
6	Hahila	Nagaon	27°27′N	92°53′E
7	Jengdia	Kamrup	26°16′N	91°46′E
8	Pobitora	Morigaon	26°12′N	91°59′E
9	Laukhoa	Dhubri	26°06′N	89°57′E
10	Sareswar	Dhubri	26°08′N	89°55′E

wetland borders on the Rupshi and Bamunijoia Reserved Forests. The southern, eastern, and western margins are cultivated with small villages scattered amongst the rice fields.

2.1.8. Laokhoa

Laukhowa Beel is located in north-western side of Gauripur town of Dhubri district of lower Assam.

2.1.9. Jengdia

The total area of this IBA is approximately 500 ha and is situated in the North of the Kamrup district, Assam. This is fresh water body with fringe of marshes which is located at the flood plains of Brahmaputra. The nearby areas are human inhabited and surrounded with hillocks covered by shrubs. This IBA is enriched with different migratory birds during the season of migration.

2.1.10. Hahila

Hahila is one of the famous wetlands of Nagaon district. Total area of the beel is 20 ha. It is a flood prone area of Kopili, surrounded by several villages and grazing fields. During monsoon, water from Nanoi and Kopili enters the beel. The beel is famous for fishes and is dense in nature.

2.2. Sample collection and analytical methods

Water sample from the following wetlands was collected and analyzed for physicochemical parameters following the established procedures of [18]. The parameters pH, EC, and TDS were monitored at the sampling site with the (pHTestr20), (ECTestr11+), and (TDSTestr11+) and other parameters like total alkalinity and total hardness (titrimetric method), chloride (silver nitrate method), nitrate (phenoldisulfonic acid method) and sulfate (turbidimetric method) were analyzed in the laboratory. Calcium, magnesium, sodium and potassium were analyzed in Systronics Flame photometer 128.

Table 2
Water Quality Index (WQI) and its status according to [23] and [24]

Water Quality Index Level	
0–25	Excellent water quality
26–50	Good water quality
51–75	Poor water quality
76–100	Very poor water quality
>100	Unsuitable for drinking

2.3. Water quality rating and weightage

WQI was first formulated by [19,20]. Method given by [19] was later on followed with slight modifications by [21,22]. The WQI level and the water quality status is represented in Table 2. The weighted arithmetic index method has been used for the calculation of WQI. Further quality rating or sub index (Qn) was calculated using the following expression:

$$Qn = 100 \times [Vn - Vo]/[Sn - Vo] \quad (1)$$

where Qn = Quality rating for the nth water quality parameter, Vn = Estimated value of the nth parameter at a given sampling station, Sn = Standard permissible value of the nth parameter, Vo = Ideal value of nth parameter in a pure water. (i.e. 0 for all other parameters except the parameter pH).

Unit weight was calculated by a value inversely proportional to the recommended standard values Sn of the corresponding parameters:

Table 3
Relative weight of the parameters

Parameter	Standard values (Sn)	Ideal value (Vo)	Unit weight (Wn)
pH	6.5–8.5	7	0.2188
HCO_3^-	120	0	0.0155
TH	300	0	0.0062
EC	300	0	0.371
TDS	500	0	0.0037
Ca^{2+}	75	0	0.025
Mg^{2+}	30	0	0.061
Cl^-	250	0	0.0074
SO_4^{2-}	150	0	0.0124
NO_3^-	45	0	0.0413
Na^+	200	0	0.057
K^+	200	0	0.057

Table 4
Average concentration of parameters in pre-monsoon

	DB	KNPw	Maguri	Hahila	Samaguri	Saran	Pobitora	Jengdia	Laokhoa	Sareswar
ph	7.63	7.56	7.2	7.57	7.36	7.32	7.55	7.1	7.12	7.16
HCO_3^- (mg/l)	31.45	27.01	18	15	10.21	12.11	17.63	15.7	13.33	12.47
TH (mg/l)	34.48	29.36	20.89	17	16.28	22.45	21.6	16.5	19.29	15.77
EC (μS/cm)	158.75	146.57	66	57	128	90	100	122	22	48
TDS (mg/l)	101.6	81.64	42.24	36.48	81.92	57.6	64	78.08	25.89	30.63
Ca (mg/l)	8.15	9.01	1.5	2.9	5.5	5	4.78	1.9	1.2	3
Mg (mg/l)	3.04	2.66	2.82	2.56	2.13	2.34	3	1.6	1	1.89
Cl (mg/l)	12.97	12.95	6	5.8	7.6	8.2	7.5	6.9	6.5	5.9
SO_4 (mg/l)	4.86	12.7	34.8	3.7	5.4	12.4	11.3	2.3	1.1	1.7
NO_3 (mg/l)	0.26	0.16	0.09	0.68	0.1	1.56	0.16	0.25	0.16	0.07
Na (mg/l)	12.71	5.69	2.54	0.5	6.5	3.3	2	3.76	3	3.9
K (mg/l)	3.9	4.67	1.2	1.1	2.56	2.89	1.5	2.9	2.73	1.1

$$\mathrm{Wn} = K/\mathrm{Sn} \quad (2)$$

where Wn = Unit weight for the nth parameter. Sn = Standard value for nth parameter. K = Constant for proportionality. The Sn, Vo and Wn values are given in Table 3.

The overall WQI was calculated by aggregating the quality rating with the unit weight linearly:c

$$\mathrm{WQI} = \Sigma \mathrm{Qn\ Wn}/\Sigma W \quad (3)$$

2.4. Statistical analysis

The statistical software package SPSS 15 window was used for correlation coefficient and multivariate analysis of the data.

2.4.1. Pearson's correlation

The correlation matrix of the data was built to find out the associations between the variables. Significant positive correlations can be explained in terms of common source or chemical similarity [25]. Thus, significant positive correlation could indicate a common source for the pairs.

2.4.2. Principal component analysis (PCA)

PCA provides information on the most meaningful parameters which describe the whole data-set interpretation, data reduction and summarize the statistical correlation among constituents in the water with minimal loss of original information [26,27]. In this study, PCA of the normalized variables were executed to extract significant principal components (PCs) and to further reduce the contribution of variables with minor significance; these PCs were subjected to varimax rotation generating factors [28]. PCs were defined according to the criterion that only factors that account for variance greater than one should be included. The rationale for this is that any component should account for more variance than any single variable in the standardized test score space [29]. Hence, PCA was applied using varimax rotation with Kaiser Normalization. By extracting the eigenvalues from the correlation matrix, the number of significant factors and the percent of variance explained by each of them were calculated.

2.5. Ion chemistry

A hydrogeochemical investigation of the wetlands has been carried out here to determine the major ion chemistry and their sources to understand the role of weathering and other geochemical processes (precipitation and dissolution of minerals/salts, redox processes, etc.) in controlling the water composition of the wetlands.

3. Results and discussion

3.1. Physicochemical properties

The average concentration of the parameters in pre-monsoon and post-monsoon are given in Tables 4 and 5. pH is the indicator of acidic and alkaline condition of water status [30] have suggested 6.5–8.5 range of pH for water for any purposes in that respect; the ranges indicate moderately alkaline water of the wetlands. In all the wetlands, pH in pre-monsoon was lower than post-monsoon due to the water levels and concentration of nutrients in water [31]. Similar observations have been recorded by [32–34] on different water bodies.

Electrical conductivity is the water capability to transmit electric current and serves as tool to assess the purity of water [35]. This ability depends on the presence of ions, their total concentration, mobility, valence, relative concentrations, and temperature of measurement [36]. Conductivity of the wetlands was significantly different among sampling sites, varying from 22 to 169 μS/cm. High conductivity at DB and wetlands of Kaziranga National Park (KNPw) in post-monsoon indicates the mixing of sewerage in river water [32] recorded similar findings in Chandlodia Lake.

Solids refer to the suspended and dissolved matter in water. They are very useful parameters describing the chemical constituents of the water and can be considered as edaphic relation that contributes to productivity within the water body [37]. TDS further indicates the salinity behavior of river water. TDS in water originates from natural sources, sewage, urban run-off, industrial wastewater and chemicals used in the water treatment process. The highest TDS is recorded in DB and KNPw during post-monsoon due to the addition of organic matter and solid waste into the lake [38].

Bicarbonates in surface water are primarily a function of carbonate, hydroxide content and also include the contributions from borates, phosphates, silicates, and other bases. Highest HCO_3^- in DB indicates the sewerage mixing in the wetland. Post-monsoon season recorded higher HCO_3^- due to high nutrients in water [39].

TH is a very important property of water from its domestic application point of view. Hardness in water is due to the natural accumulation of salts of mainly calcium and magnesium. There is a moderate variation in TH contents among different sampling sites and a trend of higher TH was found at major polluted site in DB due to mixing of domestic effluents in the wetland water. Also, anthropogenic activities might be responsible for higher TH at this site. The similar trend of TH increasing in summer was established by [9,40].

Calcium is one of the most abundant ions in fresh water and is important in shell construction, bone building, and plant precipitation of lime. The higher calcium content may be due to mixing of urban run-off and industrial wastewater. The lowest amount of calcium in water was recorded during post-monsoon due to calcium absorbed by the large number of organisms for shell construction, bone building, and plant precipitation of lime [41]. Similar trend was observed in [32,40].

Magnesium is often associated with calcium in all kinds of waters, but its concentration remains generally lower than the calcium. Magnesium is essential for chlorophyll growth and acts as a limiting factor for the growth of phytoplankton. The lowest value was recorded during pre-monsoon due to the magnesium essentiality for chlorophyll bearing plant for photosynthesis [42].

The high chloride reported in post-monsoon may be due to frequent run-off loaded with contaminated water from the surrounding area and evaporation of water [40]. Similar to our present observation [43,44], also reported high chloride in post-monsoon. The high content of chloride may also be due to storage of the accumulated sewage during rainy season coupled with decaying process that accomplished by the microbes [8,45].

Sulfate and nitrate are important parameters of surface water showing the pollution status and

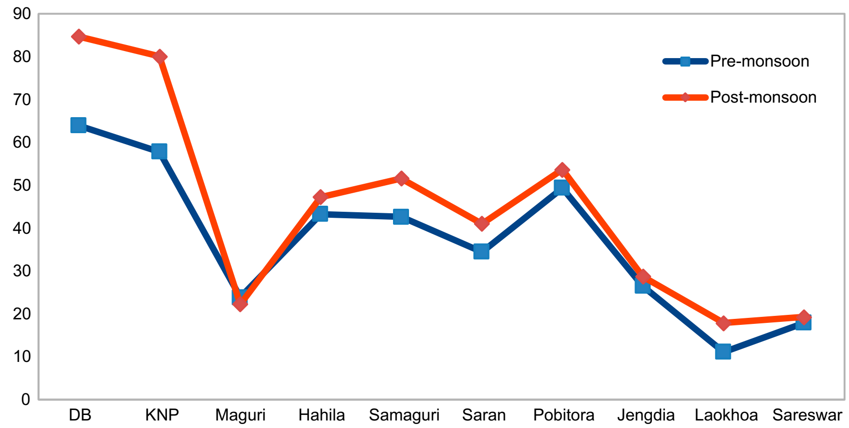

Fig. 2. WQI of the wetlands in both the season.

Table 5
Average concentration of parameters in post-monsoon

	DB	KNPw	Maguri	Hahila	Samaguri	Saran	Pobitora	Jengdia	Laokhoa	Sareswar
pH	7.97	7.88	7.17	7.6	7.5	7.4	7.59	7.2	7.17	7.24
HCO_3^- (mg/l)	45.83	31.87	19.62	21.3	13.97	16.83	21.5	20.8	15.2	14.56
TH (mg/l)	33.26	26.98	17.82	14.34	13.46	18.9	20.11	15.67	15.45	12.82
EC (μS/cm)	164.12	169.71	69	70	132	101	112	100	45	56
TDS (mg/l)	145.66	103.01	56.52	45.67	69.1	40.2	72.81	80.42	34.89	42
Ca (mg/l)	6.87	7.03	1.21	1.76	5.1	4.34	4.08	2	1.44	2.82
Mg (mg/l)	3.23	2.98	2.5	3	3	2.56	2.76	1.3	1.2	2.1
Cl (mg/l)	13.31	14.42	6	5.8	7.6	8.2	7.5	6.9	6.5	5.9
SO_4 (mg/l)	12.4	14.5	12.5	4	8.45	17.81	15.56	3.2	3.33	4.5
NO_3 (mg/l)	0.55	0.17	0.11	0.7	0.12	2	0.19	0.28	0.17	0.19
Na (mg/l)	26.42	7.81	3.2	1.4	7	3.8	2.34	4	3.5	4.3
K (mg/l)	3.87	3.99	1.67	0.7	2.1	2.2	1.32	1.3	2.34	1

Table 6
Correlation matrix of the parameters

	pH	HCO_3^-	TH	EC	TDS	Ca	Mg	Cl	SO_4	NO_3	Na	K
pH	1											
HCO_3^-	.758[b]	1										
TH	.636[b]	.805[b]	1									
EC	.696[b]	.661[b]	.653[b]	1								
TDS	.682[b]	.808[b]	.698[b]	.900[b]	1							
Ca^{2+}	.717[b]	.563[b]	.758[b]	.828[b]	.688[b]	1						
Mg^{2+}	.779[b]	.525[a]	.485[a]	.567[b]	.457[a]	.575[b]	1					
Cl^-	.735[b]	.803[b]	.880[b]	.837[b]	.796[b]	.878[b]	.469[a]	1				
SO_4^{2-}	.179	.21	.294	.188	.095	.133	.512[a]	.170	1			
NO_3^-	.105	−.059	.044	−.007	−.128	.072	.434[a]	.018	.162	1		
Na^+	.589[b]	.800[b]	.676[b]	.625[b]	.815[b]	.564[b]	.360	.696[b]	.036	−.031	1	
K^+	.413	.557[a]	.772[b]	.686[b]	.642[b]	.744[b]	.143	.869[b]	.032	.022	.588[b]	1

[a]Correlation is significant at the 0.05 level.
[b]Correlation is significant at the 0.01 level.

Table 7
Rotated component matrix obtained from PCA

Parameters	Rotated component matrix		Communality
	I	II	
pH	.751	.430	.749
HCO_3^-	.853	.167	.756
TH	.863	.187	.780
EC	.874	.167	.792
TDS	.913	.007	.834
$Ca2^+$	.849	.191	.757
Mg^{2+}	.477	.765	.812
Cl^-	.955	.093	.921
SO_4^{2-}	.072	.779	.613
NO_3^-	−.088	.495	.253
Na^+	.827	−.042	.685
K^+	.829	−.176	.718
Eigen values	7.159	1.510	
Variance (%)	59.65	12.58	
Cumulative % of variance	59.65	72.24	

anthropogenic load in any water. The highest amount of nitrate was recorded during post-monsoon because of high vegetation during winter which supported the growth of plankton [46]. The lowest amount of nitrate in water was recorded during pre-monsoon due to the utilization by plankton and aquatic plants [47].

High sulfate in Maguri beel and KNPw may be due to application of sulfur-based fertilizers in tea gardens and agricultural run-offs.

In general case, sodium is the dominant ion among the cations and is present in most of the natural waters, which contributing approximately 53–69% of the total cations. This is because of the silicate weathering and/or dissolution of soil salts stored by the influences of evaporation, anthropogenic activities, agricultural activities, and poor drainage conditions. The higher contribution of sodium than that of the contribution of calcium to the total cations is expected due to influence of ion exchange.

3.2. Water quality index (WQI)

WQI of the wetlands is established from various important physicochemical parameters in two different seasons, (Fig. 2). WQI showed excellent water quality in Maguri beel, Laokhoa beel and Sareswar beel; good water quality in Hahila, Samaguri, Saran, Pobitora, and Jengdia; and poor water quality in DB and KNPw in pre-monsoon season. In post-monsoon, DB and KNPw showed very poor water quality, whereas Maguri, Laokhoa, and Sareswar have excellent water quality; in Hahila, Saran, and Jengdia, water quality was good and lastly poor water quality was recorded in Samaguri and Pobitora. It is also observed that pollution load is higher in post-monsoon season. Deepor beel (DB) and KNPw recorded the first and second highest values of WQI, respectively, in both the seasons, indicating the most polluted of all the wetlands studied. The common source of pollution for both the wetlands may be the surrounding agricultural activities, where lots of agrochemicals are used and the nearby National highway from where anthropogenic chemicals are released to the wetland through surface run-offs.

Table 8
Characterization of surface water on the basis of Piper trilinear diagram

Subdivisions of the diamond	Characteristics of corresponding subdivision of diamond-shaped fields
1	Alkali earth (Ca^{2+} + Mg^{2+}) exceeds alkalies (Na^+ + K^+)
2	Alkalies (Na^+ + K^+) exceeds alkaline earth (Ca^{2+} + Mg^{2+})
3	Weak acids (CO_3^- + HCO_3^-) exceeds strong acids (SO_4^{2-} + Cl^-)
4	Strong acids (SO_4^{2-} + Cl^-) exceeds weak acids (CO_3^- + HCO_3^-)
5	Carbonate hardness (Secondary alkalinity) exceeds 50% (Chemical properties are dominated by alkaline earth and weak acids)
6	Non-carbonate hardness (Secondary salinity) exceeds 50% (Chemical properties are dominated by alkaline earth and strong acids)
7	Carbonate alkalinity (Primary salinity) exceeds 50% (Chemical properties are dominated by alkaline earth and weak acids)
8	Carbonate alkalinity (Primary alkalinity) exceeds 50% (Chemical properties are dominated by alkalies and weak acids)
9	Mixed types (No cation–anion pairs exceeds 50%)

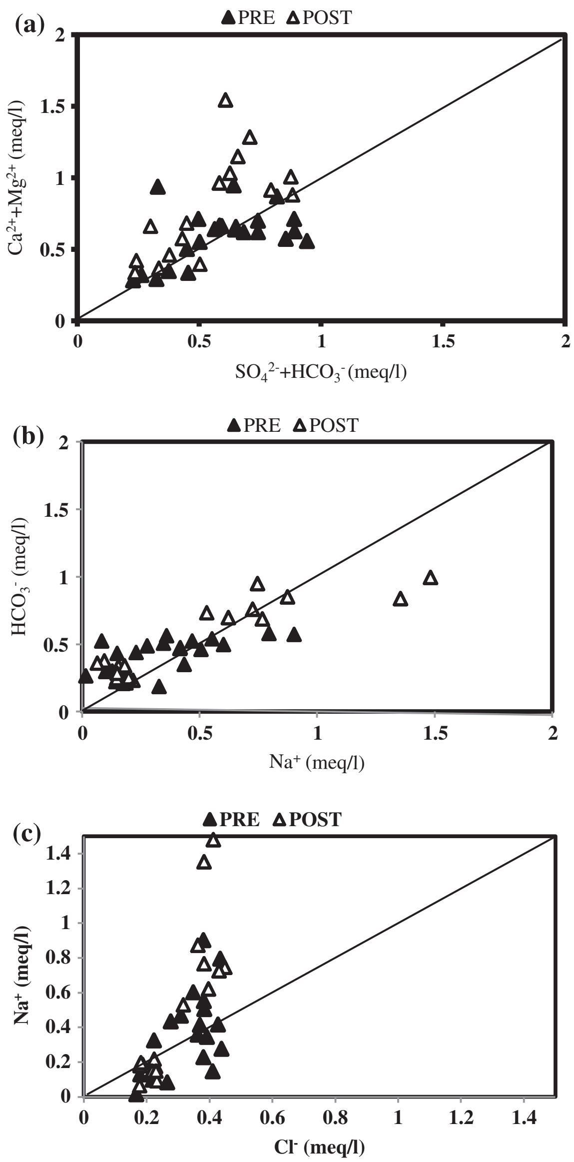

Fig. 3. Scatter plot (a) $Ca^{2+} + Mg^{2+}$ vs. $SO_4^{2-} + HCO_3^-$, (b) HCO_3^- vs. Na^+, and (c) Na^+ vs. Cl^-.

3.3. Pearson's correlation

As shown in (Table 6), a positive correlation is found among pH, HCO_3^-, TH, EC, TDS, Ca^{2+}, Mg^{2+}, Na^+, K^+, and Cl^-, which may indicate a common source of origin like weathering of rocks. Mg^{2+} also shows a positive correlation with SO_4^{2-} and NO_3^-, depicting a common anthropogenic source like fertilizers and pesticides. There is no significant correlation among SO_4^{2-} and NO_3^- which may be due to a different nature of anthropogenic source of nitrate like untreated sewage in addition to run-off from surrounding agricultural fields.

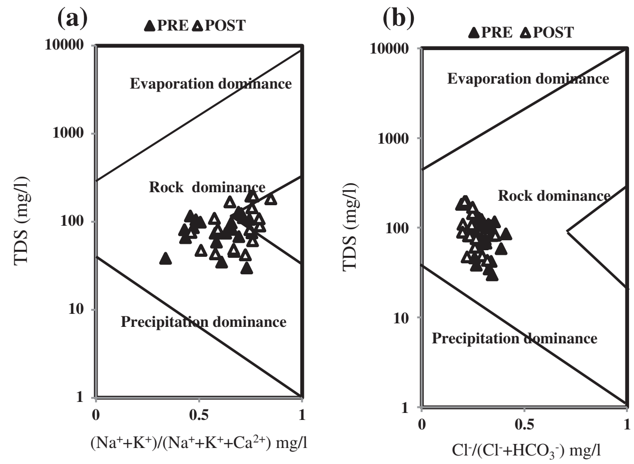

Fig. 4. Gibbs plot (a) TDS vs. $(Na^+ + K^+)/(Na^+ + K^+ + Ca^{2+})$ and (b) TDS vs. $Cl^-/(Cl^- + HCO_3^-)$.

3.4. Principal component analysis

Table 7 shows the rotated component matrices obtained from principal component analysis. PC1 (eigenvalue 7.15) represent 59.65% of the total variability in one axis which has strong positive loadings on pH, HCO_3^-, TH, EC, TDS, Cl^-, Ca^{2+}, Mg^{2+}, Na^+, and K^+. PC1 can be interpreted as a mineral component of the wetland water and is associated with weathering and solute acquisition processes in the catchment [48] stated that this clustering variables points to a common origin for these minerals, likely from dissolution of limestone and gypsum soils which can be simplified as soil erosion.

PC2 (eigenvalue 1.51) accounts for 12.58% of the total variance and has strong positive loading on Mg^{2+}, NO_3^-, and SO_4^{2-}. This factor accounts for anthropogenic origin, particularly from fertilizer application in the agricultural fields and tea gardens in the vicinity of the wetlands [49]. Non-point pollution caused by fertilizers and pesticides used in agriculture, often dispersed over large areas, is a great threat to water bodies. Intensive use of chemical fertilizers in farms and indiscriminate disposal of human and animal waste on land result may also contribute to this factor.

3.5. Ion chemistry of the wetlands

The order of the abundance of the major cation and anion is as follows: $HCO_3^- > SO_4^{2-} > Cl^- > Na^+ > Ca^{2+} > K^+ > Mg^{2+} > NO_3^-$ in pre-monsoon and $HCO_3^- > SO_4^{2-} > Cl^- > Na^+ > Ca^{2+} > Mg^{2+} > K^+ > NO_3^-$ in post-monsoon.

The plot of $Ca^{2+} + Mg^{2+}$ vs. $SO_4^{2-} + HCO_3^-$ proposed by [50] will be close to the 1:1 line when the dominant reactions in a system are dissolutions of calcite, dolomite, and gypsum. Ion exchange tends to

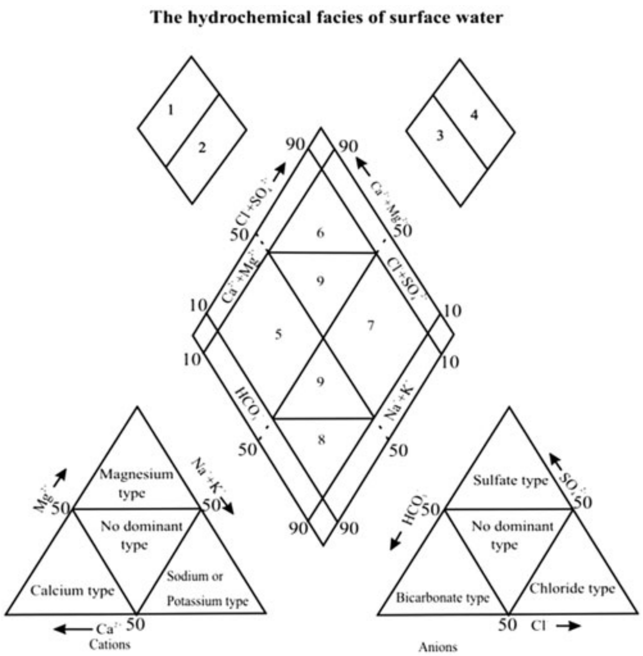

Fig. 5. Classification diagram for anion and cation facies in the form of major-ion percentages. Water types are designed according to the domain in which they occur on the diagram segments [56,57].

shift the points to right due to an excess of $SO_4^{2-} + HCO_3^-$ [51,52]. If the process is reverse ion exchange, it will shift the points to the left due to a large excess of $Ca^{2+} + Mg^{2+}$ over $SO_4^{2-} + HCO_3^-$. The plot of $Ca^{2+} + Mg^{2+}$ vs. $SO_4^{2-} + HCO_3^-$ (Fig. 3(a)) shows that most of the water samples of the post-monsoon are found above the 1:1 line except few samples which do indicate reverse-ion exchange but extent is very less, i.e. carbonate weathering was predominant than silicate weathering. While in pre-monsoon, it is evenly distributed on both sides but reverse ion tends to dominant over ion-exchange.

Higher bicarbonate concentration over sodium is indicative of silicate weathering [52]. HCO_3^-/Na^+ plot (Fig. 3(b)) of the water samples also indicated a higher extent of carbonate weathering during post-monsoon.

In the plot of Na^+/Cl^- sample points along 1:1, equiline indicates halite dissolution, however, Na^+/Cl^- ratio more than 1.0 indicates the occurrence of silicate weathering [53]. The plot of Na^+ vs. Cl^- (Fig. 3(c)) shows that both carbonate and silicate weathering occurs in the water but with a slight predominance of carbonate weathering in post-monsoon.

Carbonate weathering was found to be more dominant in post-monsoon season, which may be due to

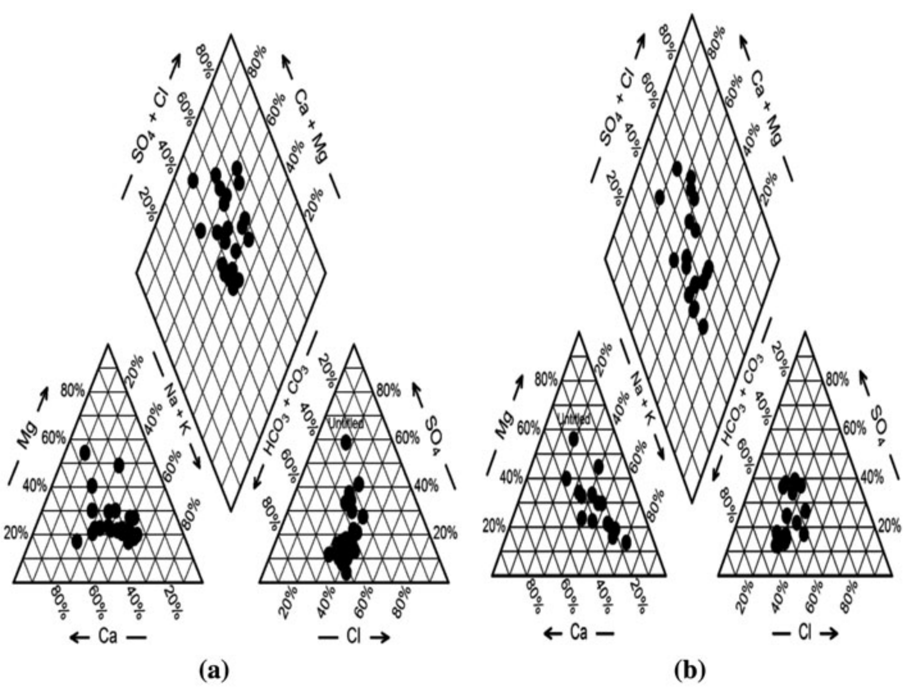

Fig. 6. Piper trilinear diagram for major ion analyses of surface water samples from the study area: (a) pre-monsoon and (b) post-monsoon.

more dissolving of the carbonate minerals by the infiltrating water which reach the subsurface in the post-monsoon followed by the monsoon season.

In order to determine the controlling mechanism of the surface water chemistry in terms of dissolved ions present in water as evaporation-crystallization dominance, rock-weathering dominance, and atmospheric-precipitation, we have plotted the hydrochemical data according to the variation in the ratios of $(Na^+ + K^+)/(Na^+ \; K^+ + Ca^{2+})$ and $Cl^-/(Cl^- + HCO_3^-)$ as function of TDS [54].

The Gibbs plot (Fig. 4(a) and (b)) shows weathering to be the dominant process in both the seasons. This indicated that the chemical composition of this water were mainly controlled by weathering reactions and can be modified from the underlying biotite schists (medium grade metamorphic rock), biotite gneisse (high grade metamorphic rock), and granite or dissolution of carbonate and silicate minerals.

The Piper trilinear diagram [55] was used to plot the chemical data of the representative samples from the study areas to infer hydrochemical facies in order to understand and identify the suitability of water composition in different classes, as well as to bring out the chemical relationships in more definite terms rather than other possible plotting methods. The waters were classified into hydrochemical facies indicating water types based on the subdivisions of the Piper-trilinear diagram suggested by [56,57] which were shown in Fig. 5 and Table 8. The Piper-trilinear diagram of water classification scheme (Fig. 6(a) and (b)) revealed that in pre-monsoon, alkali-earth $(Ca^{2+} + Mg^{2+})$ exceeded alkali elements $(Na^+ + K^+)$ and strong acids $(SO_4^{2-} + Cl^-)$ exceeds weak acids (HCO_3^-). The waters are mostly of the mixed types $(Ca^{2+}–Mg^{2+}–Cl^-–SO_4^{2-})$ and no cation–anion pairs exceed 50%. In post-monsoon, the water is dominated by alkaline earth and weak acids. The water is of mixed type $(Ca^{2+}–Mg^{2+} –SO_4^{2-}$ and $Ca^{2+}–Mg^{2+}–HCO_3^-)$.

4. Conclusion

Physicochemical properties of the surface water of the wetlands with seasonal variation are studied. The order of the abundance of the major cation and anion is as follows: $HCO_3^- > SO_4^{2-} > Cl^- > Na^+ > Ca^{2+} > K^+ > Mg^{2+} > NO_3^-$ in pre-monsoon and $HCO_3^- > SO_4^{2-} > Cl^- > Na^+ > Ca^{2+} > Mg^{2+} > K^+ > NO_3^-$ in post-monsoon. The scatter plots of $Ca^{2+} + Mg^{2+}$ vz. $SO_4^{2-} + HCO_3^-$; HCO_3^- vs. Na^+; and Na^+ vs. Cl^- shows that both carbonate and silicate weathering occurs, although carbonate weathering was much dominant in post-monsoon. According to Gibbs diagram, the predominant samples fall in the rock–water interaction dominance. The piper trilinear diagram shows that surface water in the study area is mixed type, i.e. $(Ca^{2+}–Mg^{2+}–Cl^-–SO_4^{2-}$ in pre-monsoon and $Ca^{2+}–Mg^{2+}–SO_4^{2-}$, and $Ca^{2+}–Mg^{2+}–HCO_3^-$ in post-monsoon. Based on the WQI classification, DB and KNPw are of poor water quality and are the most polluted wetlands of the Brahmaputra valley. PCA source apportionment indicated pH, HCO_3^-, TH, EC, TDS, Cl^-, Ca^{2+}, Mg^{2+}, Na^+, and K^+ as a mineral component of the wetland water whereas Mg^{2+}, NO_3^-, and SO_4^{2-} originated from anthropogenic sources.

Acknowledgment

The authors would like to thank UGC for supporting the work though the Major Research Project (UGC-MRP), Grant no. 41-1119/2012 (SR).

References

[1] A.G. Jhingran, V. Pathak, Ecology and Management of Beels in Assam—A Case Study of Three Beels, pp. 16–36. In Compendium of Workshop on Development of Beel Fishery in Assam, Assam Agricultural University, Khanapara, Guwahati, 1987.

[2] National Wetland Atlas, Ministry of Environment and Forests, Govt. of India, As a part of the project on National Wetland Inventory and Assessment (NWIA), ISRO, Ahmedabad, 2011.

[3] B. Khalil, T.M.B. Ouarda, Statistical approaches used to assess and redesign surface water-quality-monitoring networks, J. Environ. Monit. 11 (2009) 1915–1929.

[4] H. Pejman, G.R.N. Bidhendi, A.R. Karbassi, N. Mehrdadi, M.E. Bidhendi, Evaluation of spatial and seasonal variations in surface water quality using multivariate statistical techniques, Int. J. Environ. Sci. Technol. 6 (2009) 467–476.

[5] J. Nouri, A.R. Karbassi, S. Mirkia, Environmental management of coastal regions in the Caspian Sea, Int. J. Enviro. Sci. Technol. 5 (2008) 43–52.

[6] R. Noori, M.S. Sabahi, A.R. Karbassi, A. Baghvand, H.T. Zadeh, Multivariate Statistical analysis of surface water quality based on correlations and variations in the data set, Desalination 260 (2010) 129–136.

[7] J. Lewin, M.G. Macklin, Metal mining and floodplain sedimentation in Britain, in: V. Gardiner (Ed.), International Geomorphology, Part 1, Wiley, Chichester, 1987.

[8] R. Kumar, R.D. Singh, K.D. Sharma, Water resources of India, Curr. Sci. 5 (2005) 794–811.

[9] T. Medudhula, C. Samatha, C. Sammaiah, Analysis of water quality using physicochemical parameters in lower manair reservoir of Karinagar district, Andhra Pradesh, Int. J. Environ. Sci. 1 (2012) 172–180.

[10] N. Kapil, K.G. Bhattacharyya, Spatial, temporal and depth profiles of trace metals in an urban Wetland system: A case study with respect to the deepor beel, Ramsar site 1207, India, Environ. Pollut. 2 (2013) 51–72.

[11] M. Islam, A.M. Ahmed, B. Barman, S. Dakuaand, D. Debnath, Studies on physico-chemical properties of water in some selected sites of deepor beel (Ramsar site), Assam, India, The Clarion 3 (2014) 25–32.

[12] K.G. Bhattacharyya, N. Kapil, Impact of urbanization on the quality of water in a natural reservoir: A case study with the deepor beel in Guwahati city, India, Water Environ. J. 24 (2010) 83–96.
[13] S. Roy, J.C. Kalita, Detection of toxic heavy metals in the waters of deepar beel, Ramsar site, Assam, NeBIO 4 (2013) 31–34.
[14] T. Bortamuly, S. Bordoloi, Wetlands of Sivasagar district of Assam as congenial habitat for Amphibia, in: M. Sengupta, R. Dalwani (Eds.), Proceedings of Taal: The 12th World Lake Conference, 2007, pp. 525–528.
[15] D. Sarma, J. Das, A. Dutta, Ecology of two riverine wetlands of Goalpara district, Assam in relation to plankton productivity, Int. J. Appl. Biol. Pharm. 4 (2013) 219–225.
[16] K.C. Bhuyan, A. Dutta, B. Kalita, Hydrobiology and fishery status of Sondoba beel, Morigaon, Assam, J. Inland Fish. Soc. India 41 (2009) 48–53.
[17] R. Bordoloi, Comparative study on fish and fisheries of a closed and an open type wetland of the Brahmaputra valley, Int. J. Sci. Res. Publ. 4 (2014) 1–11.
[18] APHA, Standard Methods for Examination of Water and Waste Water, twenty first ed., American Public Health Association, Washington, DC, 2005.
[19] R.K. Horton, An index number for rating water quality, J. Water Pollut. Cont. Fed. 37 (1965) 300–306.
[20] W.R. Ott, Environmental Indices- Theory and Practice, Ann Arbor Science, Inc., Ann Arbor, MI, 19, 1978.
[21] T.N. Tiwari, M. Mishra, A preliminary assignment of water quality index to major Indian rivers, Indian J. Environ. Prot. 5 (1985) 276–279.
[22] R.K. Trivedy, P.K. Goel, Chemical and Biological Methods for Water Pollution Studies, Environmental Publication, Karad, India, 1986.
[23] C. Chaterjee, M. Raziuddin, Determination of water quality index (WQI) of a degraded river in asanol industrial area, Raniganj, Burdwan, West Bengal, Nat. Environ. Pollut. Technol. 2 (2002) 181–189.
[24] F.J. Thakor, D.K. Bhoi, H.R. Dabhi, S.N. Pandya, N.B. Chauhan, Water quality index (WQI) of pariyej lake district Kheda, Gujarat, Curr. World Environ. 6 (2011) 225–231.
[25] E.J. Knudson, D.L. Dvewer, G.D. Christian, T.V. Larson, Application of Factor Analysis to the Study of Rain Chemistry in the PUGET Sound Region in Chemometrics: Theory and Application, Kowalski, Washington, DC, 1977.
[26] B. Helena, R. Pardo, M. Vega, E. Barrado, J.M. Fernandez, L. Fernandez, Temporal evolution of groundwater composition in an alluvial aquifer (Pisuerga River, Spain) by principal component analysis, Water Res. 34 (2000) 807–816.
[27] D.A. Wunderlin, M.P. Diaz, M.V. Ame, S.F. Pesce, A.C. Hued, M.A. Bistoni, Pattern recognition techniques for the evaluation of spatial and temporal variations in water quality, A case study: Suquia river basin (Cordoba-Argentina), Water Res. 35 (2001) 2881–2894.
[28] S. Shrestha, F. Kazama, Assessment of surface water quality using multivariate statistical techniques: A case study of the Fuji river basin, Japan, Environ. Modell. Software 22 (2007) 464–475.
[29] E.M. de Andrade, H.A.Q. Palácio, I.H. Souza, R.A. de Oliveira Leão, M.J. Guerreiro, Land use effects in groundwater composition of an alluvial aquifer (Trussu river, Brazil) by multivariate techniques, Environ. Res. 106 (2008) 170–177.
[30] BIS, Standards for Water for Drinking and Other Purposes, Bureau of Indian Standards, New Delhi, 1983.
[31] J. Narayana, E.T. Puttaiah, D. Basavaraja, Water quality characteristics of Anjanapura reservoir near Shikaripur, District Shimoga, Karnataka, J. Aqua. Biol. 23 (2008) 59–63.
[32] U.M. Qureshimatva, R.R. Maurya, S.B. Gamit, R.D. Patel, H.A. Solanki, Determination of physico-chemical parameters and water quality index (WQI) of Chandlodia lake, Ahmedabad, Gujarat, India, J. Environ. Anal. Toxicol. 5 (2015) 2–6.
[33] R.S. Ambasht, Ecosystem study of a tropical pond in relation to primary production of different vegetation zones, Hydrobiologia 12 (1971) 57–61.
[34] T. Petre, Limnology and fisheries of Nyumba ya mung, a manmade lake in Tanzania, Afr. J. Trop. Hydrobiol. Fish. 4 (1975) 39–50.
[35] A. Murugesan, A. Ramu, N. Kannan, Water quality assessment from Uthamapalayam municipality in Theni District, Tamil Nadu, India, Pollut. Res. 25 (2006) 163–166.
[36] S.E. Shinde, S.A. Pathan, K.S. Raut, D.L. Sonawane, Studies on the physico-chemical parameters and correlation coefficient of Harsool-savangi Dam, District Aurangabad, India, Middle-East J. Sci. Res. 8 (2011) 544–554.
[37] M.E.M. Goher, Chemical Studies on the Precipitation and Dissolution of Some Chemical Element in Lake Qarun, PhD Thesis, Faculty of sciences, Al- Azhar University, Egypt, 2002.
[38] B. Moss, The influence of environmental factors on the distribution of freshwater algae: An experimental study: II. The role of pH and the carbon dioxide-bicarbonate system, J. Ecol. 61 (1973) 157.
[39] A.U. Uduma, Physico-chemicalanalysis of the quality of sachet water consumed in Kano metropolis, Am. J. Environ. Energy Power Res. 2 (2014) 1–10.
[40] P. Moharana, A.K. Patra, Studies on water quality index of Bay of Bengal at Digha, West-Bengal, India Indian J. Sci. Res. 5 (2014) 71–76.
[41] H.A. Solanki, Status of Soils and Water Reservoirs near Industrial areas of Baroda: Pollution and Soil—Water Chemistry, Lap Lambert Academic Publishing, Germany, 2012.
[42] S.K. Pawar, J.S. Pulle, Studies on physico-chemical parameters in Pethwadaj dam, Nanded District in Maharashtra, India J. Aqua. Biol. 20 (2005) 123–128.
[43] B.P. Mishra, B.S. Tripathi, Seasonal variation in some physico-chemical parameters of river Ganga water as influenced by sewage discharge, Indian J. Ecol. 30 (2003) 27–32.
[44] A. Zafar, N. Sultanab, Seasonal analysis in the water quality of the river Ganga, J. Curr. Sci. 2 (2008) 217–220.
[45] I. Longkumer Imnatoshi, S.U. Ahmed, Icthyofaunal diversity of Do Yang river system of Nagaland, Nat. J. Life Sci. 7 (2010) 1–6.
[46] B.R. Pandit, H.A. Solanki, Drinking water quality and techniques for recharging urban water system for the industrial city of Gujarat, India, in: Innovative Modelling of Urban Water Systems, Monograph No. 12, CHI, Guelph, 2012.

[47] P.U. Verma, D. Chandawat, H.A. Solanki, Study of water quality of Hamirsar Lake, Bhuj, Int. J. Biosci. Report 2 (2010) 145–153.
[48] M. Vega, R. Pardo, E. Barrado, L. Debán, Assessment of seasonal and polluting effects on the quality of river water by exploratory data analysis, Water Res. 32 (1998) 3581–3592.
[49] C. Reimann, P. de Caritat, Distinguishing between natural and anthropogenic sources for elements in the environment: Regional geochemical surveys versus enrichment factors, Sci. Total Environ. 337 (2005) 91–107.
[50] P.S. Datta, S.K. Tyagi, Major ion chemistry of groundwater in Delhi area: Chemical weathering processes and groundwater flow regimes, J. Geol. Soc. India 47 (1996) 179–188.
[51] T.E. Cerling, B.L. Pederson, K.L.V. Damm, Sodium-calcium ion exchange in the weathering of shales: Implications for global weathering budgets, Geology 17 (1989) 552–554.
[52] S.R. Fisher, W.F. Mullican III, Hydrochemical evolution of sodium-sulfate and sodium-chloride groundwater beneath the Northern Chihuahuan Desert, Trans-Pecos, Texas, USA, Hydrogeol. J. 5 (1997) 4–16.
[53] M. Meybeck, Global chemical weathering of surficial rocks estimated from river dissolved loads, Am. J. Sci. 287 (1987) 401–428.
[54] R.J. Gibbs, Mechanism controlling world water chemistry, Science 17 (1970) 1088–1090.
[55] A.M. Piper, A geographic procedure in the geochemical interpretation of water analysis, Trans. Am. Geophys. Union 25 (1944) 914–923.
[56] W. Back, Techniques for mapping of hydro-chemical facies, United States geological survey water supply paper, 424–D (1961) 380–382.
[57] B.B. Hanshaw, Chemical geohydrology in: Advances in hydro science, Academic Press, New York, NY, 1965.