Review Article

An Assessment Of Water, Soil Quality And Biotic Communities Of The Floodplain Wetlands Of The Brahmaputra And Barak Valley Of Assam, India- A Review

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Abstract: An assessment of water, soil quality and biotic communities of floodplain wetlands of the Brahmaputra and Barak Valley of Assam has been reviewed. Brahmaputra valley was found to be more conducive to biological production than that of beels of the Barak valley. The beels of north bank districts of the Brahmaputra valley were relatively more productive compared to the south bank. In general, productivity in terms of phytoplankton density was poor in all the beels of Assam. A rich growth of marginal and submerged vegetation was observed in the floodplain wetlands of Brahmaputra basin. Geochemical characteristics of surface water have been reported for pH, electrical conductivity, total dissolved solids, bicarbonate, chloride, sulphate, nitrate, calcium, magnesium, sodium, potassium and total hardness. The order of the abundance of the major cation and anion is as follows: $HCO3^{-}>SO_4^{2-}>Cl^{-}>Na^{+}>Ca^{2+}>K^{+}>Mg^{2+}>NO_3^{-}$ in pre-monsoon and $HCO_3^{-}>SO_4^{2-}>Cl^{-}>Na^{+}>Ca^{2+}>Mg^{2+}>K^{+}>NO3^{-}$ 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 indicated 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 samples 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 (WQI) on some wetlands of the Brahmaputra valley, Deepor Beel and wetlands of Kaziranga National Park shows poor water quality.

Key words: Barak valley, Brahmaputra, Macrophytes, Planktons, Sediment, Wetlands

Introduction

Wetlands are unique and complex ecosystem in the landscape that play a critical role in regulating the movement of water within watersheds as well as in the global water cycle (Mitsch and Gosselink, 1993; Richardson, 1994). They serve as sources, sinks and transformers of elements and compounds. The biogeochemical processes by which nutrient are assimilated into the system are important in evaluating the nutrient condition of the wetland (Mulholland and Kuenzler, 1979; Mitsch and Gosselink, 2000; Raymond and Bauer, 2001; Bouchard, 2007). Before 20th century, words like bog, billabog, swamp, marsh, fen, mire, moor, peatland, mangrove, carr, lagoon, bottomland etc. were used to describe wetlands. The word ‘wetland’ was first used in 1956 in an essay about wetlands in United States of America. Ramsar Convention on Wetlands, defines wetlands as “areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters”. However, it is not easy to define wetland very precisely because of their great geographical extent and the wide variety of hydrologic conditions in which they are formed. Wetlands have often been described as being ecotones, that is, transition zones between two biomass such as uplands and deepwater aquatic systems, where two communities meet and integrate. It is a key characteristic of the landscape in almost all parts of the world and sometimes described as the "Kidneys of the Landscape". Wetlands may function as organic exporters or inorganic nutrients sinks and often leads to high biodiversity, which 'borrow' species from both aquatic and terrestrials systems (Keddy, 2000). They have some characteristic of deepwater systems such as algae, benthic invertebrates, nekton, anoxic substrate and water movement and at the same time they also have vascular plant flora similar in structure to those found in uplands. Some wetlands, because of their connections to both upland and aquatic systems, have the distinction of being among the most productive and biologically diverse ecosystems on Earth (Mitsch and Gosselink, 1993).

World's wetland is estimated to occupy nearly 7 to 9 million km^2, or about 4 to 6 percent of the land surface of the Earth and is made up of mangroves, high-altitude lakes, marshes, flood plains and ponds (Maltby and Turner, 1983). Almost 56% of this estimated total wetlands area is found in tropical (2.6 million km^2) and subtropical (2.1 million km^2) regions. India has rich variety of wetland habitat. The extent of the India's wetlands (excluding rivers) is 58,286,000 ha, or 18.4% of the country's geographic area, of which 70% is under paddy cultivation. There are eight different categories of wetlands in India differentiated by region. East and north east India is blessed with 2.02 lakhs ha of wetlands (Sugunan and Bhattacharjya, 2000).

Assam has 3,513 wetlands covering a total area of 101,231.6 ha. These natural assets are mostly found in floodplains of the river Brahmaputra and Barak basin. Of these, 3,388 wetlands are natural with a total area of 98,819.6 ha. This is close to 4 per cent of the total floodplain area and 1.3 per cent of the total area of the state. The lakes/ponds occupy an area of 15494 ha and number 690. There are 861 oxbow lakes covering 15461 ha. The water logged areas number 1126 and occupies 23436 ha (dry season satellite data). The swamps and marches cover an area of 43434 and number 712 (Baruah *et al.*, 2000). All natural wetlands are called beels in Assam. In 1992, the Assam remote sensing application centre, ASTEC and the space research organisation developed a classification system for the wetlands in Assam that divide them into six categories (1) lake/pond (2) Oxbow lake (3) Water-logged areas (4) Swamp/Marsh (5) Reservoir and (6) tank. The first four are natural water bodies while the last two are human-made. Natural wetlands sometimes have feeder channels controlling the inflow of water. Most of the swampy lands in Assam are formed as ox-bow lakes or abandoned channel scattered all over the active flood plains of the river systems. A few of these water bodies, however, owe their origin to depressions caused as result of earthquakes.

Beels constitute vitally important fishery resource of Assam. The wetlands of Assam were highly productive in terms of fish diversity and are considered as life support systems which provide tremendous economic benefits to people living around. Besides the Brahmaputra and the Barak river system, beels are the major source of fish in Assam (Baruah *et al.*, 2000). There is increasing need to highlight the chemical, physical, and biological processes operating in the floodplain wetland of Assam in order to assess their ecosystem function and services. The present review provides an overview of the status of the major nutrients, physico-chemical, hydrogeological aspects of water and soils and biological communities of the wetlands in order to assess their productivity.

Study area

Assam is one of the 7 states of northeast India. It extends between the latitudes of 24°8′ N - 28°2′ N and longitudes of 89°42′ E - 96° E. The T-shaped state is sprawled in an area of 78,438 km^2. It is bordered by the Indian states of Arunachal Pradesh, Nagaland, Manipur, Mizoram, Tripura, Meghalaya, and West Bengal (National Wetland Atlas).

Geology of study area

According to (Geological survey of India, 2009), the state can be broadly divided into the following physiographic domains: (a) Brahmaputra valley (b) Central Assam Hills (c) Barak valley.

The geological history of the region directly or indirectly involves almost all the major geological ages from the Archean to the recent (Nandy, 1975) and the state of Assam is occupied by rocks belonging to (a) Proterozoic Gneissic Complex (b) Shillong Group of Meso-Palaeo Proterozoic age (c) Granite Plutons of Neo-Proterozoic-Lower Palaeozoic age (d) Lower Gondwana sedimentary rocks of Permo-carboniferous age (e) Alkali complexes of Samchampi, Borpung and volcanic rocks represented by Sylhet Trap of Cretaceous age (f) Lower tertiary (Paleocene-Eocene) shelf sediments of the Jaintia group extending along the southern and eastern flanks of Mikir Hills and geosynclinals sediments of Disang group in parts of the North Cachar Hills (g) Upper tertiary (Oligocene to Pliocene) shelf and geosynclinal sediments covering the southern flanks of Mikir Hills, the North Cachar Hills and the hills of the Cachar district in the Surma valley area. These rock area are also exposed along the northern foothills of Naga-Patkai range bordering the southern margin of Sibsagar, Jorhat and Dibrugarh districts. Along the southern foothills of eastern Himalaya facing the northern border of Assam narrow strip of Siwalik rocks are exposed (h) The Quaternary deposits comprising of older and newer alluvium occur in flood plains and terraces of the Brahmaputra valley, Surma valley and other river basins of Assam (Geological survey of India).

Climate of Assam: Assam experiences the predominant influence of the southwest tropical monsoon rainforest climate, which is normally active from April to October. The approach of the monsoon is usually marked by strong winds, overcast skies accompanied by occasional thunder showers, hailstorms and at times by cyclones between April and May. Heavy downpour starts from June. The annual average rainfall of the state varies between 160 cm and 430 cm from place to place. The average rainfall for the state as a whole is about 290 cm with maximum precipitation during June and July. The average temperature in the state varies from 4°C to 19°C during the winter and 26°C to 37°C during the summer accompanied by high humidity (Geological survey of India, 2009).

Characteristics of wetlands in Assam

High productivity of the wetland ecosystem can be related to the efficient conversion of the solar energy into organic carbon in the presence of rich nutrients available from natural sources. The productivity rate of floodplain wetlands of Assam are many times higher than those reported from other inland open water ecosystems of India (Sugunan and Bhattacharjya, 2000). The main characteristics of wetland of Assam are as follows:

1. A substantial portion of the each of the floodplain wetland of Assam is covered by rooted vegetation with arenchymous tissue in their stems. This allows oxygen to transport into the root area and creates an aerobic zone predominantly within the reducing environment in saturated soils.
2. Wetland soils shift from an aerobic condition during winter when wetlands are completely or partially dry up to an anaerobic, or reduced, condition during monsoon.
3. Wetland soil of Assam is acidic in nature.

Soil quality and different soil parameters of wetlands of Assam

Hydric soils are formed under conditions of saturation, flooding or ponding long enough during the growing season to develop anaerobic conditions in the upper part, is another characteristic of wetlands (Reddy *et al.*, 2008). Factors like climate of wetlands, change of water bodies, structure of the lands, green plants etc determine the nature of hydric soil in wetlands. Four factors such as redox reactions, aerobic decomposition, leaching and dehydration determine the properties of the wetland soil. During the dry condition of the soil, it oxidizes all the elements due to presence of oxygen. But during flood, the oxygen in the pores of the soils gets replaced by water resulting in hypoxia or anoxia state. Therefore, chemical reactions shift towards reduction reaction. Aerobic decomposition also stops and anaerobic conditions develop in the upper part of the soil.

Based on oxidation reduction processes in the soil, it is divided into two types- peat and muck soil. In the muck soil, the aquatic plants decompose completely and develop a black colour. On the other hand, decomposition is not completed in the peat soil and it develops a brownish colour. SO_4^{2-} in the organic soil reduces to H_2S and releases a smell of rotten egg. In such reducing conditions, Fe^{3+} reduces to Fe^{2+} and Mn^{4+} reduces to Mn^{2+} imparting a greenish ash or bluish ash colour to the soil. This is called *Gley* colour and the soil is called *Gleyed* soil. Gleyed soil is an important feature of the wetland hydric soil. Wetland soils serve as sites for many biogeochemical transformations. They also provide long and short term storage of nutrients for wetland plants (Reddy *et al*., 2008).

The soil pH is one of the principal factors for determining wetland productivity since it controls most of the chemical reactions in the ecosystem. Near neutral to slightly alkaline soil pH (7 and a little above) is considered to be ideal for fish production. The soil pH of beels of Assam ranges from 4.2 to 6.5 (Kar *et al*., 1990, Acharjee *et al*., 1998, Sugunan and Bhattacharjya, 2000, Bordoloi *et al*., 2012) Soil of all the beels except that of Moridisoi (Golaghat) and Motapang (Tinsukia) were acidic in nature. This is considered unfavourable for fish production as well as microbial activity. Moreover, low pH can reduce the availability of key nutrients in the system and lower its fertility. Brahmaputra valley showed slightly higher mean soil pH (5.3) than beels of the three Barak valley districts (5.0). Beels of the upper Assam districts had the lowest mean soil pH followed by Central Assam and Lower Assam. It was observed that beels in the north bank of the Brahmaputra had higher soil reaction in comparision to beels in the South bank. (Sugunan and Bhattacharjya, 2000). According to Banerjee (1967) productivity of a pond also depends on organic carbon and classified the ponds into low (OC<0.5%), medium (OC 0.5–1.5%) and highly productive (OC >1.5%) systems.Wide range of variation (3.4-39.0 g/kg) was observed in the organic carbon content of the soil of Assam (Kar *et al*., 1990; Sugunan and Bhattacharjya, 2000; Das *et al*., 2011). This variation is dependent on the quantity of macrophytes present in the beels and their magnitude of decomposition. The mean values of soil organic carbon indicated that the beels of the Brahmaputra valley were more productive than those of Barak valley in respect of soil organic matter. Beels in the south bank of the Brahmaputra valley showed comparatively high mean value of soil organic carbon than the lakes in the north bank. Central Assam had higher average values followed by upper Assam and lower Assam (Sugunan and Bhattacharjya, 2000).

Available soil nitrogen status is the easily oxidisable form of total nitrogen in the soil and is influenced largely by the organic matter content of the soil. Available N impacts the productivity of the wetland. The following concentrations of available N in mg/100 g and their productivity was given by (Banerjee, 1967): Low <25, Medium 25–50, High >50. Available nitrogen values ranged from 145 to 410 mg/l (Sugunan and Bhattacharjya, 2000; Das *et al*., 2011). It was rather low in the beels of both the Brahmaputra valley and the Barak valley from a fisheries point of view. The low available nitrogen of soils is mainly due to reduced microbial activities and slow rate of decomposition of soil organic matter on account of the prevailing acidic reaction of the soil. Beels of the Brahmaputra valley had higher mean value of available nitrogen compared to the Barak valley. Beels of central Assam showed highest mean value of available nitrogen, followed by lower and upper Assam (Sugunan and Bhattacharjya, 2000). Available soil phosphorus is an important factor in influencing the aquatic productivity. Available P_2O_5 and their productivity levels range from: low <3, medium 3-6, high >6 mg/100 g respectively (Banerjee, 1967). Available soil phosphorus was rather poor in most of the beels and the value range between 0.8 and 27.0 mg/ kg (Sugunan and Bhattacharjya, 2000; Das *et al*., 2011). Such low level of available soil phosphorus is attributable to the presence of macrophytes, especially the rooted ones which rapidly uptake most of the available phosphorus. Beels of the Brahmaputra valley has higher level of available phosphorus (14.5 mg/kg) compared to the Barak valley (8.5 mg/kg) (Sugunan and Bhattacharjya, 2000). Beels of Central Assam had the highest mean value of available-P followed by lower and upper Assam (Das *et al.*, 2011). A range of 0.15-1.93 mg/100 g of available-P was recorded in the Sone beel of Assam (Kar, 1990). Available phosphorus varied between 35 and 50, 42 and 52 and 35 and 110 mg/kg in Dighali, Dora and Ghorajan respectively (Acharjee *et al.*, 1998). Phosphate was recorded in a range of 0.11-0.8 mg/l in Potiasola beel indicating a low productivity (Bordoloi *et al.*, 2012).

Water Quality and different parameters of wetlands of Assam

Wetlands mostly receive water from three sources: precipitation, surface flow and groundwater. An open wetland receives water mostly from surface flow and can exchange large amount of water and materials between the wetland and adjacent non-wetland ecosystems. On the other hand, a "closed" wetland system receives water only from precipitation and can exchange very little materials with adjacent terrestrial or aquatic ecosystems. Wetlands that receive primarily groundwater inputs tend to have high concentrations of dissolved inorganic constituents such as calcium (Ca) and magnesium (Mg). The main process by which wetland hydrology is governed:

atmospheric deposition+ surface water flow+ ground water flow to wetlands(discharge)= evaporation + precipitation+ wetland water flow to ground water (recharge)+transpiration.

In floodplain wetlands, water quality is influenced to a great extent, by inflow of water from the connecting rivers, local catchment area and by the metabolic processes of plants and animals living within the water body (Sugunan and Bhattacharjya, 2000). Water temperature is a regulatory factor for various physico-chemical as well as biological activities in a wetland. In several studies of physico-chemical parameters of the wetlands of Assam, water temperature of the beels ranges from 4 to 35^{0}C (Acharjee *et al.*, 1998; Kar, 2008; Das *et al.*, 2011; Sarma *et al.*, 2012; Sarma *et al.*, 2013). The quantity, quality, intensity and duration of light influence the life of organisms in different ways. Secchi disc visibility varied between 11 and 132 cm (Sugunan and Bhattacharjya, 2000; Kar, 2008; Paswan *et al.*, 2012; Sarma *et al.*, 2013).

The pH of water which ranged from 6.0 to 8.2 (mean value of 7.1) was influenced mainly by basin soil and by aquatic vegetation. It followed more or less similar trend of variation of soil pH. Most of the beels of the Barak valley had acidic water. In the Brahmaputra valley, beels of upper Assam recorded the low average value of water pH (7.0) compared to lower and central Assam (Acharjee *et al.*, 1998; Kar, 2008). In Hasila wetland of Goalpara district, pH values were estimated between 8.0 and 8.5. It was lowest in winter and highest in pre-monsoon (Sarma *et al.*, 2013). The lower pH during winter season was due to high turbidity as well as the uniform temperature during that season. This might have enhanced microbial activity, causing excessive production of CO_2 and reduce the pH value (Wetzel, 1975; Khan and Khan, 1985).

Dissolved oxygen is the most important parameter which can be used as an index of water quality, primary production and pollution. Dissolved oxygen content is the most significant factor regulating metabolic processes of the organism and also the community as a whole. Dissolved oxygen in general affects the solubility and activity of various nutrients and therefore, the productivity of an aquatic ecosystem. The dissolved oxygen levels of water of most of the beels were fairly high and within the optimal range for the growth of fishes. The values range between 4.0 and 9.5 mg/l in the beels of the Barak valley with a mean of 7.8 mg/l and between 4.0 and 13.6 mg/l, with a mean of 7.9 mg/l in the beels of the Brahmaputra valley (Sugunan and Bhattacharjya, 2000; Das *et al.*, 2011; Paswan *et al.*, 2012; Sarma *et al.*, 2012; Sarma *et al.*, 2013). Free carbon dioxide levels were low in most of the beels which range between 1.0 and 19.6 mg/l with a mean value of 4.0 mg/l (Sugunan and Bhattacharjya, 2000; Kar, 2008; Bordoloi *et al.*, 2012; Paswan *et al.*, 2012; Sarma *et al.*, 2012; Sarma *et al.*, 2013). The variations in the concentrations of dissolved oxygen and free carbon dioxide were mainly due to the rate of photosynthetic activity by aquatic vegetation and variation in the organic matter content in the basin soil (Paswan *et al.*, 2012).

The levels of total alkalinity, hardness and specific conductivity of water in beels of Assam varied widely and the values range from 16.0 to 227.0 mg/l, 10.0 to 169.0 mg/l and 18.0 to 354.0 µmhos/cm respectively (Sugunan and Bhattacharjya, 2000; Kar, 2008; Bhattacharyya *et al.*, 2010; Das *et al.*, 2011; Paswan *et al.,* 2012; Sarma *et al.,* 2013; Dutta *et al.*, 2016). It was observed that the mean values of' total alkalinity, hardness and specific conductivity in the beels situated at the Brahmaputra valley were twice that of Barak valley. In the Brahmaputra valley, beels of the North bank districts recorded higher mean values of total alkalinity, hardness and specific conductivity than those of the South bank districts (Sugunan and Bhattacharjya, 2000).

Dissolved organic carbon content of all the beels of Assam were relatively high, the values ranging between 0.8 and 5.0 mg/l (Sugunan and Bhattacharjya, 2000; Das *et al.*, 2011).

All the beels of Assam under scrutiny were poor in the major nutrients viz. nitrogen and phosphorus. The concentrations of NO_3-N range from traces to 0.08 mg/l and that of P_2O_5 from traces to 0.08 mg/l. Such low values of nitrogen and phosphate is common in water bodies where these nutrients are rapidly absorbed by the rich plant communities. In beels, the quick turnover of these nutrients takes place due to heavy infestation of macrophytes during monsoon (Sugunan and Bhattacharjya, 2000). The PO_4-P concentration of water ranged from trace to 0.03 mg/l in the beels of Sivasagar district and trace to 0.04 mg/l in the beels of Jorhat district respectively. The NO_3-N ranged from 0.01-0.03 mg/l in both the districts (Das *et al.*, 2011).

Hydro-geochemistry of wetlands of Assam

In a study of geochemical characteristics of surface water of ten different wetlands of the Brahmaputra valley of Assam by Dutta *et al.* (2016) namely Deepor beel, wetlands of Kaziranga National Park, Maguri, Samaguri, Saran, wetland of Pobitora wildlife sanctuary, Sareswar, Laokhoa, Jengdia and Hahila, the order of abundance of the major cation and anion was 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 (Dutta and Tyagi, 1996) 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 shift the points to right due to an excess of $SO_4^{2-}+HCO_3^-$ (Fisher and Mullican, 1997). 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 $Ca^{2+}+Mg^{2+}$ versus $SO_4^{2-}+HCO_3^-$ (Fig. 1a) 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 (Fisher and Mullican, 1997). HCO_3^-/Na^+ plot (Fig. 1b) of the water samples also indicated a higher extent of carbonate weathering during post monsoon.

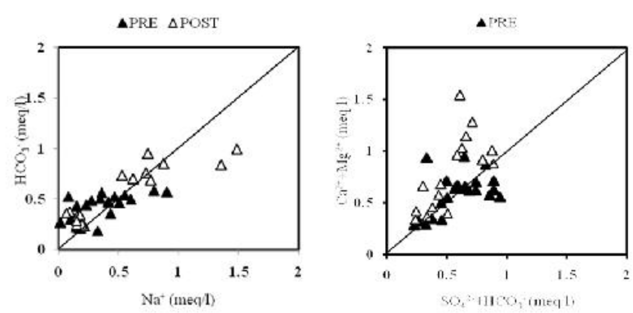

Fig. 1. Scatter plot (a) HCO_3^- vs. Na^+ (b) $Ca^{2+}+Mg^{2+}$ vs. $SO_4^{2-}+HCO_3^-$

Both carbonate and silicate weathering occured in the wetlands although carbonate weathering was found to be dominant in post-monsoon. According to Gibbs diagram (Gibbs, 1970), (Fig. 2 a, b) the predominant samples fall in the rock-water interaction dominance. This indicated that the chemical composition of these 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.

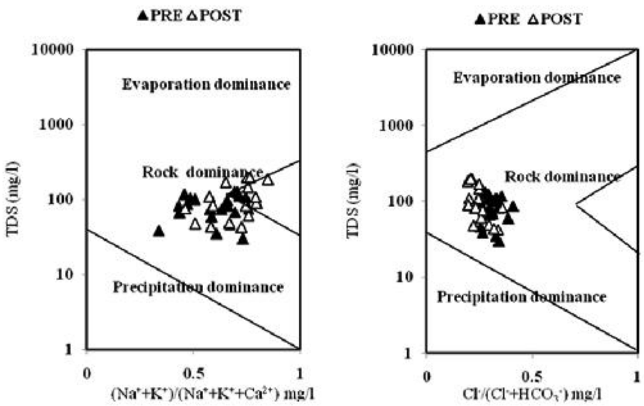

Fig. 2. Gibbs plot (a) TDS vs. (Na++K+)/ (Na++K++Ca2+) (b) TDS vs. Cl-/ (Cl- +HCO3-)

The Piper- trilinear diagram by Piper (1944) (Fig. 3 a, b) 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 (Dutta *et al.*, 2016).

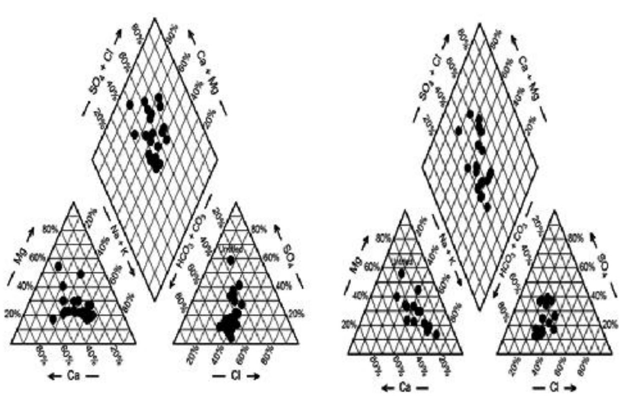

Fig. 3. Piper trilinear diagram for major ion analyses of surface water
(a) Pre-monsoon (b) Post-monsoon

Water Quality Index (WQI) of wetlands of Assam

WQI of the wetlands is calculated from various important physicochemical parameters in two different seasons by Dutta *et al.* (2016) (Fig. 4), first formulated by (Horton, 1965 and Ott, 1978) for the above mentioned wetlands. WQI showed excellent water quality in Maguri, Laokhoa and Sareswar; good water quality in Hahila, Samaguri, Saran, Pobitora and Jengdia; and poor water quality in Deepor beel and Kaziranga National Park in pre monsoon season. In post monsoon Deepor beel and Kaziranga National Park wetlands 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.

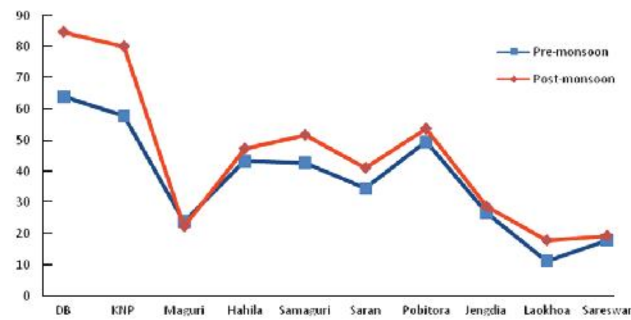

Fig. 4. WQI of the wetlands in pre and post-monsoon.

Wetland biotic communities of Assam

The unique water renewal pattern of the ecosystem influences the abundance and succession of biotic communities occupying the wetlands. The organisms inhabiting this system comprise a complex mix of lotic and lentic communities. The dynamic ecological character brought in by the cyclic changes in the lake morphometry, water chemistry and sediment characteristics leads to some unique faunal and floral associations. Biotic communities of beels, thus adapt themselves to spatial and temporal fluctuation leading to a high degree of floral and faunal diversity (Sugunan and Bhattacharjya, 2000).

i. Planktons

Plankton comprises microscopic organisms (both plants and animals) with very limited or no power of locomotion. They move about and drift in water purely at the mercy of water movements. Phytoplankton bearing photosynthetic pigments makes use of the rich inorganic nutrients available in the beel ecosystem and synthesizes organic matter (autotrophs). Thus, they form the base of ecological pyramid. Zooplankton, on the other hand live on the huge reserve of organic matter of plants or animal origin, both in live and dead form (detritus). Thus, zooplankton is the secondary producer linking the phytoplankton with the communities occupying higher trophic levels. Zooplankton plays a vital role in making efficient use of dead and living organic matter in the wetlands.

Out of three zones viz. upper, central and lower Assam in Brahmaputra valley, beels in the later two zones exhibited better abundance of plankton as compared to upper zone. Density of plankton in the beel of upper zone varied between nil to 84 µl. Phytoplankton group was generally represented by *Chlorophyeae, Baclllariophyceae* and *Myxophyceae.* Zooplanktons were represented by *Ostracoda, Copepoda, Cladocera* and *Rotifera* (Sugunan and Bhattacharjya, 2000).

In general, productivity in terms of phytoplankton density was poor in all the beels of Assam. Although low pH, transparency and conductivity are attributable to the low plankton concentration, the predominant factor is the competition with macrophytes in garnering sunlight and nutrients. Moderate to high level of infestation of various categories (emergent, submerged, floating etc.) of macro vegetation were always associated with low plankton count. The relatively high plankton count in central and lower Assam beels is attributable to the low altitude with sloppy gradient of the Brahmaputra. The order of domination of various classes of phytoplanktons in central Assam zone is as follows: *Chlorophyceae* > *Dinophyceae* > *BacilIariophyceae* > *Myxophyceae* >*Euglenophyceae* (Sugunan and Bhattacharjya, 2000). Forty seven different forms of phytoplankton and 19 different forms of zooplankton were recorded till date in the Sone beel (Kar, 1990). Eighteen species of zooplankton was recorded in the Chatla Haor of Cachar district (Kar and Barbhuiya, 2004). It has been observed in both Hasila and Urpod beels the member of *Chlorophyceae* dominant throughout the year (Sarma *et al*., 2013). Dominance of *Chlorophyceae* throughout the year indicates indicates excess of nutrient such as Nitrogen and Phosphorus (Round, 1973).

ii. Macrophytes

A unique feature of the floodplain wetlands of Brahmaputra basin is the prosperous growth of marginal and submerged vegetation due to nutrient loading. These macrophytes often tend to replace the plankton community. Progressive replacement of plankton community with macrophytes as the main primary producer hastens the pace of eutrophication. This also leads to higher rate of evapotranspiration and swampification of the lake. However this process can be reversed through effective management. Dense mat formation by marginal and floating macrophytes was observed in beels like Mota beel (Tinsukia). Udaipur beel in the same district is choked with water hyacinth. Open beels like Gala beel (Golaghat district) were almost free from weed infestation. However, Samrajan north in the district of Dhemaji has a good standing crop of macrophytes despite being an open beel (Sugunan and Bhattacharjya, 2000). Aquatic macrophytes (AM) of Sone beel were found to exhibit a heterogenous assemblage of 23 species in the beel. AM biomass in Sone beel was found to vary from 0.58 – 21.90 kg/m^2 (average 2.48 ± 0.82) having the maximum in December and the minimum in May (Dey and Kar, 1989a). *E.crassipes* was the sole perennial species in the wetland, followed by *H. verticillata* and *T. bispinosa* occurring during most of the months of the year. During dry season, the emergent varieties (*E. stagnina, E. acutangula, S. eriophorum, O. sativa, S. trifolia* and *P. flaccidum*) and the submerged types (*H. verticillata, T. bispinosa, V. spiralis*) generally succeed, flourish and show abundance when the wetland exhibits a decreasing trend in its depth.

In a study of AM of Baskandi Anua River-formed Wetland (Dhar *et al*., 2004) 16 species of AM have been recorded in the 39.2 ha (at FSL) Baskandi Anua which belong to 6 free-floating (*Azolla pinnata, Echhornia crassipes, Salvinia cucullata, Lemna pausicostata, Pistia stratiotes, Wolfia* sp); 2 rooted submerged (*Hydrilla verticillata, Vallisneria spiralis)*; 6 rooted with floating leaves (*Nymphaea nouchali, Nymphoides indicum, N.cristatum, Trapa bispinosa, Euryale ferox, Nelumbo nucifera*) and 2 rooted emergent (*Jussiaea repens, Muradania* *nudiflora*). Of these, 6 AM species were found to occur throughout the year. These are *Azolla pinnata, Eichhornia crassipes, Salvinia cucullata, Trapa bispinosa* and *Jussiaea repens.* Twenty three species of AM was recorded in the Chatla haor in the Cachar district of Assam (Kar and Barbhuiya, 2001). Twenty nine species belonging to 28 genera and 21 families were represented in Dighali beel while Dora beel recorded 27 species of 26 genera and 20 families. In Ghorajan beel, there were 28 species of 28 genera and 21 families. Macrophyte biomass ranged between 115.34 and 207.95 g^{-2} (Av. 164.27 g^{-2}) in Dighali, while for Dora, it varied from 108.6 to 200.8 g^{-2} (Av. 156.3 g^{-2}) and Ghorajan 133.5 to 230.9 g^{-2} (Av. 181.4 g^{-2}). Commonly encountered species in the three beels were *Hydrilla verticellata, Potamogeton octondrus, Eichhornia crassipes, Saivinia cucullata, Najas indica, Vallisneria spiralis* and *Trapa bispinosa* (Acharjee *et al.*, 1998). Total of 26 aquatic macrophytes belonging to six ecological classes were recorded in the Goronga beel. Altogether four free floating macrophytes were recorded, out of which *Eichhornia crassipes* was the dominant one (Sarma *et al.*, 2012).

Conclusion

A brief study about the hydro-geochemistry of the wetlands of Assam showed that carbonate weathering is prevailing over silicate weathering in the region. The water of the wetlands was influenced mainly by rock water interaction. The water type changes seasonally from Ca^{2+}-Mg^{2+}-Cl^{-}-SO_4^{2-} type or facies in pre-monsoon to Ca^{2+}-Mg^{2+}-HCO_3^{-} and Ca^{2+}-Mg^{2+}-SO_4^{2-} type respectively, indicating a mixed type of water in post-monsoon. Water quality index grading of some wetlands of Assam reported that Deepor beel and some of the wetlands of Kaziranga National Park are polluted to a great extent as compared to the other studied wetlands.

The important physico-chemical factors influencing aquatic productivity include pH, alkalinity, dissolved gases like oxygen and carbon dioxide and dissolved inorganic nutrients like nitrogen and phosphorus. As per report, beels of Assam is capable of producing 1000kg/ha/yr of fishes with moderate level of Management. But surprisingly, the present level of fish production is 173 kg/ha/yr average. According to the literature available, ideally, an aquaculture pond should have a pH between 6.5 and 9 as well as moderate to high total alkalinity (75 to 200, but not less than 20 mg/L) and a calcium hardness of 100 to 250 mg/L of $CaCO_3$.The beels of the Barak valley had mostly acidic water whereas that of Brahmaputra valley ranged from neutral to slightly alkaline. Alkalinity and calcium hardness ranged from low to moderate range. Therefore, by stabilizing pH at or above 6.5, alkalinity improves phytoplankton productivity by increasing nutrient availability. Agricultural limestone can be used to increase calcium concentrations (and carbonate-bicarbonate alkalinity) in areas with acid waters or soils. Agricultural gypsum (calcium sulfate) or food grade calcium chloride could be used to raise calcium levels in soft, alkaline waters. Similarly, chronically high CO_2 levels can be treated chemically with hydrated lime, $Ca(OH)_2$. Approximately 1 mg/L of hydrated lime will remove 1 mg/L of CO_2. Such adaptations are necessary for increasing the productivity of the wetlands from fishery point of view.

An evaluation of physico-chemical properties of water and soil of the wetlands of Assam indicates that in spite of some adverse conditions such as acidic nature of soil, beels in general are conducive for developing culture-based and capture fisheries. Under highly reduced conditions, the decomposition of organic matter is slow and the products of decomposition are mainly reduced or partially oxidized compounds like H_2S, CH_4 and short chain fatty acids. The production of these compounds is undesirable in as much as they make the soil strongly acidic. If it is not naturally buffered, it may reduce the rate of bacterial action, ultimately leading to less productivity. For soil, a slightly alkaline pH has been considered favorable for fish production. Soil phosphorus level below 3 mg/100 g of soil may be considered indicative of poor production and that between 3 and 6 of average production; wetlands having available phosphorus above 6 are productive. The available N range of 50-75 mg/100 g of soil may be taken as relatively more favourable. Available soil N and P was found rather poor in most of the beels of Assam, indicating low productivity. N and P fertilization management helps to cope with the required levels for optimum wetland productivity.

Productivity in terms of phytoplankton density was found to be poor in all the beels of Assam. A rich growth of marginal and submerged vegetation was observed in the floodplain wetlands of Brahmaputra basin. Progressive replacement of plankton community with macrophytes as the main primary producer hastens the pace of eutrophication. According to a report 1,367 out of 3,513 wetlands in Assam are in threat due to invasion of aquatic weeds. Instead of external fertilization, macrophyte clearance and bottom raking resulted in rich plankton growth and the highest ever production.

Thus, a fundamental understanding of the concepts and chemistry underlying the interactions of the properties of wetland water and soil is necessary for effective and profitable wetland management.

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