ICHTHYOFAUNAL DIVERSITY AND ECOLOGICAL STATUS OF BANSABATI BEEL, MURSHIDABAD DISTRICT, WEST BENGAL

A Thesis

Submitted to the

West Bengal University of Animal and Fishery Sciences

In partial fulfillment of the requirements for the Degree of

Doctor of Philosophy

in

LIFE SCIENCE

(Ichthyofaunal diversity and ecological status of Bansabati beel, Murshidabad district, West Bengal)

by

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CERTIFICATE

This is to certify that the work recorded in the thesis entitled **"ICHTHYOFAUNAL DIVERSITY AND ECOLOGICAL STATUS OF BANSABATI BEEL, MURSHIDABAD DISTRICT, WEST BENGAL"** submitted by **Arghya Kamal Mondal** in partial fulfillment of the requirement for the degree of **Doctor of Philosophy (Life Science)** in the Faculty of Fishery Sciences, West Bengal University of Animal and Fishery Sciences is faithful and bonafide research work carried out under my supervision and guidance. The results of the investigation reported in this thesis have not so far been submitted for any other degree or diploma.

The assistance and help received during the course of investigation have been duly acknowledged.

(Prof. Nagesh T. Srinivasan)
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APPROVAL SHEET

Approval of the examiners for the award of the degree of **Doctor of Philosophy in Life Science (Ichthyofaunal diversity and ecological status of Bansabati beel, Murshidabad district, West Bengal).**

We, the undersigned, have been satisfied with the performance of **Arghya Kamal Mondal** in the viva-voce examination, conducted today (Monday), the 13th February 2023, recommended that the thesis be accepted for the award of the degree.

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Abbreviations / symbols	Description
FAO	Food and Agricultural Orgaisation
kg	Kilogram
MMT	Million Metrictonn
km	Kilometer
ha	Hectare
EKW	East Kolkata Wetlands
BOD	Biological Oxygen Demand
etc	Et cetera
A.M.	Ante Meridiem
pH	Potential of hydrogen
TDS	Total Dissolved Solids
cm	Centimeter
APHA	American Public Health Association
ml	Millilitre
H_2S0_4	Sulphuric acid
mg/l	Milligram/litre
EDTA	Ethylene diamide tetra acetic acid
DO	Dissolved oxygen
NO_3-N	Nitrate nitrogen
EPA	Environment Protection Agency
NH_3-N	Ammonia nitrogen
mm	Millimeter
PO_4-P	Phosphate-phosphorus
HNO_3	Nitric acid
$SnCl_2$	Stannus chloride
G	Gram
ANOVA	Analysis of Variance
IUCN	International Union
EN	Endangered
VU	Vulnerable

Abbreviations / symbols	Description
NT	Near Threatened
LC	Least Concern
DD	Data Deficient
NE	Near Endangered
Ca	Calcium
Mg	Magnesium
$CaCO_3$	Calcium carbonate
CIFA	Central Institute of Freshwater Aquaculture
µs/cm	Microsiemens per centimetre
GVA	Gross Value Added
SAC	Space Application Center
IBI	Index of Biotic Integrity
TP	Total Phosphorus
SD	Secchi Disc
PAST	Package for Education and Data Analysis
SPSS	Statistical Package for Social Sciences
CCA	Canonical Correspondence Analysis

ABSTRACT

The research was carried out in an open wetland called Bansabati *beel* in the Murshidabad district of West Bengal from December 2020 to November 2021 to evaluate the fish diversity pattern, ecological status, trophic condition and fish-based Index of Biotic Integrity (IBI). Knowledge of fundamental aspects of ichthyofaunal diversity and eco-fishery status is essential not only to maintain a healthy aquatic ecosystem but also to develop effective management and conservation strategies. Fishes were sampled on monthly basis to study species composition, abundance, trophic guild and diversity. Fish diversity was analysed using diversity indices such as species richness index, Simpson's diversity index, Shannon- Wiener's diversity Index and Pielou's evenness index. A total of 42 fish species belonging to 21 families were recorded with the Cyprinidae family contributing the most. The beel has a great deal of promise in the native and ornamental fish trade owing to their rich diversity. Carnivorous fish species dominated the trophic guild, followed by planktivores. One fish species was found to be 'Endangered', three fish species were found to be 'Vulnerable' and three fish species were found to be 'Near Threatened' categories of IUCN Red List. Various diversity indices revealed that the *beel* has moderate to high fish diversity and evenness. The impact of anthropogenic stress on fish assemblage integrity, the index of biotic integrity (IBI), was assessed utilizing the fish community structure with 12 metrics. Traditional IBI scores (5-3-1) showed that the 'reference site' had a high fish assemblage and the highest integrity compared to other sites. With an average IBI score of 43.33, the Bansabati *beel* could be categorized as 'marginally impaired'. The study demonstrates that fish assemblage might serve as potential indicators of anthropogenic stress and its effect. Monthly analysis of physico-chemical parameters of water and soil revealed that all parameters studied were well within the tolerable limits of freshwater fishes. Overall mean value of Carlson's trophic state index (53.85) of the Bansabati *beel* suggested that floodplain wetland may be classified to be in the 'transition phase' from 'mesotrophy to eutrophy'. Among the various groups of phytoplankton, Chlorophyceae was the most dominant followed by Cyanophyceae, Bacillariophyceae and Euglenophyceae. During the study period, a total of eight species of macrophytes were recorded. The study suggested protecting the habitat by limiting the amount of human interference, scientific intervention and involvement of stakeholders in order to maintain diversity and to get sustainable ecological benefits from it.

Chapter 1

INTRODUCTION

1. INTRODUCTION

The United Nations has adopted seventeen Sustainable Development Goals (SDGs) with 169 targets and 230 indicators as a universal call to action to end poverty, protect the planet, and ensure that by 2030 all people enjoy peace and prosperity. These goals must be integrated to ensure the development with balanced social, economic and environmental sustainability. World population is expected to reach 9.8 billion by 2050 and as a result the food production must approximately double to nourish. Fisheries and aquaculture offer ample opportunities to reach some of these SDGs by reducing hunger and improve nutrition, alleviate poverty, generate economic growth and ensure better use of natural resources. Furthermore, the demand for fish is also projected to grow predominantly in developing and developed regions of the world. Over the decades, the fisheries sector has progressed from a self-effacing, conventional and sustenance level to a sophisticated, organized and modern industrial enterprise owing to various innovations, modernization in fishing crafts and gears, scientific management approaches and, policy initiatives and reforms.

India has vast and varied inland fisheries resources comprising rivers and canals (0.19 million km), reservoirs (3.15 million ha), ponds and tanks (2.41 million ha), floodplain wetlands including *beel*s, oxbow lakes and others (1.2 million ha) and brackish water (1.24 million ha) (Department of Fisheries, MFAHD, 2022a). Currently India produces 7.96% of the world's fish, making it the third-largest producer in the world. The total fish production during 2021-22 is estimated 16.24 million metric tonnes with a contribution of 11.25 million metric tonnes from inland sector (Department of Fisheries, MFAHD, 2022b). Indian also became top producer of fish from inland fisheries during 2020 (FAO, 2022). The fisheries sector contributed to 1.24% of the Gross value added (GVA) to Indian economy and 7.28% of the agricultural economy in 2019-20 (Department of Fisheries, MFAHD, 2020). Indian seafood export reached 1.3 million tonnes amounting to Rs. 57,586.48 crore during 2021-22 (MPEDA, 2022). Fisheries sector also plays a vital role in employment generation to about 16 million people.

Although inland fisheries have increased in absolute terms, their potential growth rate has not yet been reached. Among various inland water bodies, wetlands are widely considered as one of the primary life-supporting and productive ecosystems on this planet, constituting huge floral and faunal diversities (Chandrakar and Dhuria, 2020). They also impart significant ecological services and support fisheries and aquaculture activities, besides being crucial for biodiversity conservation (Panthi *et al.,* 2014) thereby maintaining ecological integrity (Kumar *et al*., 2019; Debnath *et al*., 2022). Furthermore, range of ecological services provided by wetland ecosystems also include groundwater recharge, drought prevention, soil enrichment, storm protection, water filtration, refuge for endemic and migratory biodiversity, carbon sequestration, and microclimate regulation, make them essential to the ecological balance (Kumari *et al.,* 2020). Unfortunately, such exquisite wetlands are reeling under anthropogenic stress. Conversion of wetlands into agricultural fields or other commercial purposes has not only threatened rich biodiversity (Bhakta and Bandyopadhyay, 2008; Chowdhury and Nandi, 2014) but also wetland ecosystems. Invasive species introduction, overexploitation, use of destructive fishing methods and lack of general awareness are other issues affecting biodiversity of wetlands. Therefore, there is a great need to conserve such valuable ecosystems.

Wetlands are defined in various ways. Ramsar convention (1971) as a valuable tool to encourage sustainable wetland management and conservation defines wetlands as "areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static, flowing, fresh, brackish or salt, including areas of marine water, the depth of which at low tide does not exceed six meters". The Ramsar convention on wetlands is an international treaty signed in 1971 for international cooperation on conservation of wetland and their resources. The most prevalent type of freshwater wetlands, known as floodplain wetlands, are located in low-lying areas near to large rivers with fluvial landscapes that frequently flood due to overflow from the main river channel (Sugunan *et al.,* 2000; Sarkar *et al.,* 2021) and are locally known as '*beel*' (Chattoraj *et al.,* 2016; Khongngain *et al*., 2017). Floodplain wetlands are prominent features along the Ganga, Brahmaputra and Barak river basins of India which are generally lentic in nature (Ayyappan *et al.,* 2017).

West Bengal is provided with 0.61 million ha of freshwater resources, out of which 0.41 lakh ha are *beel*s and boars (Bandyopadhyay *et al*., 2014) enriched with diverse indigenous ichthyofaunal composition that could form a vital source of fisheries or ground for aquaculture. A perusal of the literature suggested that these native fish species are on the verge of decline due to habitat loss, invasive species introduction, overexploitation and use of destructive fishing methods along with agricultural runoff leading to environmental and habitat degradation (Chakraborty *et al*., 2006; Siddik *et al*., 2014; Saha and Pal, 2019; Sarkar *et al.,* 2021). Knowledge of species composition, fish faunal distribution pattern, and their conservation status are critically necessary in order to design approaches for the revival of such valuable and ecologically relevant systems (Mogalekar *et al.,* 2017).

The quality of the water, which is determined by the physico-chemical and biological factors, is crucial for a healthy aquatic habitat. Adaptation and survival of species in aquatic ecosystem may be negatively impacted by the cyclical changes in the system's physical, chemical, and biological components. In order to comprehend an aquatic ecosystem's biological production and diversity, its physico-chemical features are crucial (Jena *et al.*, 2013). For effective fisheries management, it is also crucial to estimate the plankton density, productivity, and trophic status of lakes. Changes in the quantity, species diversity, and community composition of plankton may serve as crucial indicators of environmental changes. In a similar vein, macrophytes are also employed as a tool in the measurement of pollution and nutrient level, water quality and lake condition, and trophic status (Arya *et al.*, 2018). Each of these producers and consumers forms a crucial connection in the energy transfer to the next trophic level in the lake food chain (Sharma, 2000). It is crucial to determine a lake's trophic state because it gives lake managers a frame of reference through which to observe changes in productivity, health, and ecological status and helps them understand how to restore or protect these changes (Ghosh and Mondal, 2012).

Increasing anthropogenic pressure, discharge of partially-treated or entirely untreated industrial effluents, as well as surface run-off from agricultural land all over the globe have all contributed to the degradation of the wetlands despite the great value of ecosystem services (Prasad *et al.*, 2002). A better instrument for the quick evaluation and monitoring of the ecological status of these water bodies is required in order to build any relevant, comprehensive, ecologically sustainable, and scientific management strategy. Although there are many approaches based on the physical and chemical characteristics of water, employing biological communities to assess the state of water resources has gained importance recently (Miller *et al.*, 1988; Karr, 1991; Paller *et al.*, 1996; Crettaz-Minaglia and Juarez, 2020; Flores-Lopes and Shilling, 2022). An ecologically based metric for quantitatively evaluating the biological quality of surface waters is the index of biotic integrity (IBI) (Karr, 1981). It represents energy inputs, biological interactions, physical habitat quality, hydrological regime, land-water connections, and water quality (Karr *et al.*, 1986; Steedman, 1988; Allan *et al.*, 1997). Karr *et al.* (1986) modified the IBI to combine data from different levels (individual, population, assemblage, and ecosystem) into a single number or score and a rating for the quality of a body of water. As the IBI gained popularity, many modifications were recommended for vivid ecosystems and geographical areas such as estuaries, lakes, wetlands and taking account into regional variations in fish species (Simon and Lyons, 1995; Toham and Teugels, 1999). In India, Ganasan and Hughes (1998) in the Khan and Kshipra rivers in the country's central region, Abhijna and Kumar (2017) in lake Veli-Akkulam, South India, Das and Samanta (2006) in the freshwater zone of the Hooghly estuary, Haldar (2004) in two oxbow lakes in West Bengal, and Das *et al.* (2013) in the Ganga River have successfully assessed the IBI of their respective ecosystems using fish assemblages. Nevertheless, the application of IBI using fish assemblages in wetlands is scarce.

The river Ganga, its tributaries and distributaries collectively form the Gangetic plains of West Bengal, which is enriched with numerous floodplain wetlands along the riverine stretches of Hooghly, Bhagirathi, Churni, Jalangi, Torsha, Pagla and others. According to Das *et al*. (2020), the wetland area of Murshidabad has decreased from 0.28 lakh ha in 2001 to 0.06 lakh ha in 2020. Seasonal water logging, floodplains and marshes are most common in this region (Sugunan *et al.*, 2000). Fish and fisheries of *beel*s of Murshidabad have been studied by Sugunan *et al.* (2000) in Baloon *beel*, Mistry (2016) in Ahiran Lake, Bhattacharyya *et al.* (2017) in Bishnupur *beel* and Sarkar *et al.* (2020) in Chaltia *beel*. Bansabati *beel*, an open wetland situated at the margin of Suti-I and Raghunathganj-I Blocks of Murshidabad district, is one of the largest wetlands in Murshidabad district (Mondal, 2012). Despite its significance, there is a dearth of comprehensive biological and ecological knowledge, with the exception of Mondal (2012), who covered specific geographic elements and water flow patterns of the *beel*. The present study, the first of its kind in the Bansabati *beel*, was therefore aimed at reconnoitring the fish diversity as well as eco-fishery status of the *beel* with the following objectives

1. To assess the ichthyofaunal diversity of the Bansabati *beel*
2. To study eco-fishery status of the Bansabati *beel*
3. To evaluate the integrated biotic index for the assessment of health status of Bansabati *beel*
4. To assess the trophic status of the Bansabati *beel*

Chapter 2

REVIEW OF LITERATURE

2. Review of literature

Wetlands are ecotones or transitional zones that are found between open water bodies and the dry land (Bhattacharyya *et al.*, 2017). Wetlands are among the blue planet's most diverse and productive ecosystems because of their distinctive soil characteristics, abundant and diverse flora and fauna, and prolonged shallow water inundation (Ghermandi *et al*., 2010).They provide numerous ecological and economic benefits and, services such as providing water for irrigation, fisheries, carbon sequestration, recreation, groundwater recharge, nitrogen cycling and biodiversity preservation flood management.

Researchers from many different fields have long been interested in wetlands. While geologists, hydrologists, limnologists, and geographers have primarily studied the evolution, classification, and physical characteristics of wetlands; botanists, ecologists, and environmentalists have concentrated on their species diversity, nutrient status, and ecological behaviour. Wetlands are defined in different ways. But the widely accepted is the one as defined in the Ramsar Convention on Wetlands (1971) which defines wetlands as "areas of marsh, fen, peat, and 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." According to the Convention , wetlands that meet the criteria set out by the Ramsar Bureau and are determined to be of international significance are referred to as 'Ramsar Sites'. As of June 30, 2022, there were 2,439 Ramsar sites, totaling over 254,689,088 hectares, which is slightly more than Algeria, the tenth-largest nation in the world (Ramsar Secretariat, 2022). There are now 75 Ramsar sites in India, encompassing a total area of 13 lakh 26 thousand 677 Hectare, as the country celebrates its 75th year of independence (Ramsar Secretariat, 2022). However, several additional wetlands that serve potentially useful purposes continue to be disregarded in the development of policy. Wetlands, owing to their multi-level benefits, are continuously under anthropogenic pressure leading to habitat destruction and loss of biodiversity thereof.

Wetlands are classified in various ways by different authors. Based on their hydrological, ecological, and geological characteristics (Cowardin *et al*., 1979), wetlands are divided into marine (coastal wetlands), estuarine (including deltas, tidal marshes, and mangrove swamps), lacustrine (lakes), riverine (along rivers and streams), and palustrine ('marshy'- marshes, swamps, and bogs).

India is bestowed with a variety of distinct and unique wetland ecosystems due to its varied terrain and climate regimes (Prasad *et al*., 2002). The high altitude Himalayan Lakes are the highest point of natural wetlands in India. These lakes are followed by wetlands found in the flood plains of the main river systems, saline and transient wetlands of the arid and semi-arid regions, coastal wetlands such as lagoons, backwaters, and estuaries; mangrove swamps; coral reefs; and marine wetlands. Major rivers are directly or indirectly responsible for the majority of inland wetlands.

The range of estimates for the geographic extent of wetlands in India ranges significantly from 1% to 5% of total area; however, they do sustain about 5% of the known biodiversity (Bassi *et al.*, 2014). As per the latest inventory of Indian wetlands, Space Application Centre (SAC) reported, 15.98 million ha is the estimated total area of wetlands, or 4.86 percent of the nation's total land area. In India, 2, 31,195 wetlands in total have been mapped between 2017 and 2018. Tamil Nadu (11.6%), Maharashtra (11.2%), Andhra Pradesh (10.4%), Uttar Pradesh (8%) and Gujarat (7.6%) are the states with the highest proportion of wetlands. In terms of overall wetland area coverage, Gujarat has the largest portion (21.9%), followed by Maharashtra (7.2%), Andhra Pradesh (7.14%), West Bengal (7.07%), and Uttar Pradesh (6.9%). For the investigation of wetland ecosystems, 18 main river basins are employed. In terms of number (56000, 24.2%) and size (3.75 Mha, 23.5%), the Ganga river basin has about one-fourth of the country's wetland areas. Ganga basin contains the greatest proportion of lakes (26.6%), Ox-Bow lakes (81.1%), Riverine (76%), waterlogged natural (47.7%), River/streams (35.6%), reservoirs/barrages (22.7%), waterlogged-manmade (70.4%), and mangroves (43.9%) in the nation (Gupta *et al*., 2021).

The floodplain wetlands of West Bengal constitute 42,500 ha, or 22% of the state's total freshwater area, with individual areas ranging from 2 to 600 ha (Vinci *et al.,* 2000). Since a few years ago, the majority of *beels* have been subject to a culture-based fisheries regime. However, this resulted in excessive stocking, which had a negative impact on the ecosystem's function, productivity, and biodiversity in a number of the state's wetlands. According to Sugunan *et al*. (2000) wetlands with effective management methods, such as stocking, scheduling fishing, limiting fish size at catch, watch and ward, and flood control measures, have produced fish up to 3262 kg/ha/year.

2.1 Floodplain wetland

The floodplains are connected with rivers whose beds continually alter, particularly in the potamon regimes, and may be either permanent or temporary. A river's ability to change course often is influenced by a variety of factors, including flow rate, sediment transport rate, slope, channel layout, water and sediment yield, quantity and duration of precipitation across the catchment region, soil texture and lithology, tectonic status, and others (Sugunan *et al*., 2000).

Floodplain wetlands play vital role in fisheries and aquaculture. Various fish species including commercially important cultivable species migrate during the monsoon to breeding and feeding pastures in the floodplains that have maintained their link to the parent river. Wetlands often have richer water and sediment quality favouring higher primary production in terms of phytoplankton and macrophytes. If the appropriate management techniques are used, the high trash and nutrient input from the catchment is ideal for aquaculture practices.

Floodplain wetlands are locally called as '*beels*' in Assam, West Bengal, Arunachal Pradesh, Meghalaya, and Tripura; 'maun', 'chaurs', 'dhars' in Bihar; 'pats' in Manipur; and 'charhas' and 'boars' in northern and south-eastern West Bengal, respectively (Sugunan *et al*., 2000). Large floodplain wetlands in West Bengal are particularly important to India's inland fisheries because they sustain the lives of thousands of people. Fish production is often substantially lower than its potential despite the large area they cover. Only 12.5% of the state's large amount of wetlands (0.42 lakh ha) could be managed scientifically by fisheries, yielding 0.399 mt of production as contrast to its 1.05 mt potential (Roy *et al*., 2018).

2.2 *Beels* and their importance

Beels, the most important form of floodplain wetlands, are recognized as one of the ecologically and biologically sensitive habitats. Owing to their high nutrient profile and biological productivity, they support fisheries and aquaculture activities by providing nursery grounds for commercially important fishes and enabling natural recruitment of fishes (Sugunan *et al*., 2000), thereby contributing to rural economy.

2.3 Classification of floodplain wetlands or *beels*

Beels have been categorized in numerous ways (Sugunan *et al*., 2000) based on morphometry (ox-bow lake, lake-like wetland, tectonic depressions and meteorite lake); based on water retention capacity (perennial and seasonal), based on depth shallow, medium deep and deep *beels*); based on size (small with less than 100 ha; medium with 100-500 ha and large *beels* with more than 500 ha) and based on riverine connection (open *beels* with connection to the river channel and closed *beels* without riverine connection). Considering the above classification, the present study area, Bansabati *beel*, can be categorized as a large, shallow and perennial open *beel*.

2.4 Distribution of *beels* in West Bengal

The Gangetic West Bengal region is made up of the deltaic sections of the Ganga River, as well as its tributaries and distributaries. Here, the Ganga River travels across alluvial plains with a relatively low gradient, causing significant changes in the shape of the floodplain. The State has more than 150 *beels* with a total area of 42,000 ha, making over 22% of the state's total freshwater area (Vinci *et al.,* 2000).

Beels are distributed along all the important rivers such as Bhagirathi, Hooghly, Ichhamati, Lalangi, Churni, Kalindi, Dharub, Dharala, Pagla, Behula, Torsa and Puranabhaba The districts of 24 Parganas, Murshidabad, Cooch Behar, and Nadia have nearly half of the *beels*, with Murshidabad (45 number and total spread area 15,982 ha) and Nadia (42 number and total spread area 13,161 ha) having the highest numbers (Sugunan *et al*., 2000). Number of researchers have worked on water quality, floral and faunal diversity including fish, plankton, macrophytes, birds , *beel* production, habitat changes and geomorphology of *beels* of west Bengal (Sugunan *et al*., 2000; Mondal *et al*., 2010; Ghosh and Biswas, 2017; Bhattacharyya *et al*., 2017; Sarkar *et al*., 2020; Puthiyottil *et al*., 2021) However, because of their dynamic nature and succumb to anthropogenic stress, continuous monitoring of water and sediment quality and , faunal and floral diversity is very much necessary for sustainable ecological benefits. The following sections of this chapter deals with various researches conducted in *beels* of India in general and West Bengal in particular.

2.5 Ichthyofaunal diversity

Ichthyofaunal diversity refers to the diversity of fish species; depending on the circumstances and scale, it may also apply to all or specific genotypes within a population of fish, species of life forms within a fish community, or species of life from various aquaria (Burton *et al*., 1992). Fishes are the most diversified groups among vertebrates with about 35,000 species have been described globally till today (Froese and Pauly, 2022). India, owing to its geographical location, bestowed with an estimated 2936 fish species. Among them, 936 are freshwater species, 113 are brackish species, and 1887 are marine species (Anonymous, 2018).

Earlier, the majority of researchers on wetlands focused on birds and other aquatic fauna, and little attention is paid to fishes (Sale, 1979; Werner, 1979; Fishelson, 1980). Ichthyofaunal knowledge, thus, is a major barrier to holistic development of wetlands. Over the years, interest among the researchers has grown rapidly because of role of fisheries and aquaculture activities in augmenting food supply, employment opportunities and other ecological benefits. This growth, however, has been impaired by the loss of habitat and the introduction of alien species causing drastic decline of native fish species. Datta (2015) asserts that as a result of growing human activity in catchment regions and changes to river basins, wetlands are being overexploited, having their land used inequitably, and absorbing pollutants from a variety of sources. Due to a lack of scientific information and understanding of the standards to be used for characterizing and identifying the conservation status of vulnerable species, the conservation of freshwater fish has never been fully addressed in India. For the protection and management of the local fish fauna, an understanding of the species composition and distribution patterns of fishes is essential. Surveying the fish species and its habitats is thus necessary in order to develop strategies for their efficient production (Mogalekar *et al*., 2017).

2.5.1 Freshwater fisheries resources of West Bengal

A lake's fish diversity pattern essentially mirrors the parent river system's flora. They were created as a result of rivers shifting their courses, a phenomenon common to India's flood plains (Dey, 2017). Floodplain wetlands of India support rich biodiversity in general, and fish diversity in particular. *Beels*, because of their highly productive nature, are best suited for capture, culture and capture-cum-culture fisheries. In the case of fish fauna of open and closed varieties of *beels*, a significant contrast is perceptible. Along with fish native to this ecology, open-type *beels* are known to harbour a variety of riverine species.

According to Mogalekar *et al*. (2017), there are 267 species of freshwater fish species in West Bengal, including 186 primary species and 81 secondary species, which are divided into 12 orders, 40 families, and 123 genera. In the state's freshwater bodies, thirteen exotic fish species have been introduced. Cypriniformes was the top order with a rich species makeup (117 species, 46 genera and 4 families). 109 ornamental fish, 92 food fish, and 66 decorative or food fish were discovered in freshwater. About 48 fish species are classified as ‘threatened’ or ‘near threatened’ in the IUCN Red List.

The River Ganga, its tributaries and distributaries collectively form the Gangetic plains of West Bengal, which is enriched with numerous floodplain wetlands along the riverine stretches of Hooghly, Bhagirathi, Churni, Jalangi, Torsha, Pagla and others. According to Sugunan *et al*. (2000), the Murshidabad alone has 13612 ha of water scattered over 45 *beels* that are either directly or indirectly connected to some of the rivers. Seasonal water logging, floodplains and marshes are most common this region. Fish and fisheries of *beels* of Murshidabad have been studied by Sugunan *et al.* (2000) in Baloon, Mistry (2016) in Ahiran Lake, Bhattacharyya *et al.* (2017) in Bishnupur *beel* and Sarkar *et al.* (2020) in Chaltia, and they have reported fish diversity in the range of 16-47. Most of the authors have reported Cyprinidae as the most dominant family in the *beels* of West Bengal. Comprehensive research on the fish variety of floodplain environments from different West Bengal districts has been shown in Table 2.1.

Table 2.1 Fish diversity of floodplain wetland from various districts of West Bengal

Authors	Locality	Fish diversity reported
Mandal and Kaviraj (2009)	Gopalnagar and Dumar of Bongaon subdivision in the North 24-Parganas district	49 species; 23 genera
Das *et al*. (2013)	Rasik *beel* in the district Coochbehar	53 species; 22 families
Mistry *et al*. (2016)	Ahiran wetland in Murshidabad district	47 species; 18 families
Ghosh and Biswas (2017)	Chhariganga oxbow lake located in Nakashipara development block of Nadia district	33 species; 17 families
Bhattacharyya *et al*. (2017)	Bishnupur *beel*, a horse shoe lake at Berhampore in Murshidabad district	33 species
Dey (2017)	Patan wetland situated in Murshidabad district	54 species
Das (2018)	Bochamari *beel* of Cooch Behar district	40 species; 31 genera; 15 families
Pal *et al*. (2018)	Panishala *beel* of Cooch Behar district	39 species; 28 genera; 16 families
Sarkar and Saha (2021)	Hasadanga *beel*, Nadia district	34 species; 26 genera; 16 families

2.6 Diversity indices

According to Ghosh and Biswas (2017) seasonal mean value of Shannon Index (SWI), Species evenness, Simpson's diversity index of Chhariganga oxbow lake of the Gangetic river basin, West Bengal, were 1.68, 0.51 and 0.67 respectively. Das (2018) reported that Shanon index of general diversity and evenness index in Bochamari *beel*, Coochbehar district, West Bengal ranged from 1.735 to 2.876 and 0.640 to 0.822. Triparna *et al*. (2021) observed Shanon-Wiener index and evenness index of Muragacha *beel*, West Bengal, were ranging from 2.762 to 2.796 and 0.858 to 0.868. According to Sarkar and Saha (2021) Shanon-weaver species diversity index, Margalef's species richness index, Pielou's species evenness index and Simpson's index of dominance, were ranging from 1.2911-1.3502, 12.72-14.15, 0.8829-0.9140 and 0.05346-0.07139 respectively in Hasadanga *beel*, Nadia district, West Bengal. Sarkar *et al*. (2020) reported Shanon-wiener index and Simpson's index ranging from 2.89 (Chandania) to 3.09 (Bhomra) and 0.93 (Mathura and Chandania) to 0.94 (Bhomra) in floodplain wetlands, West Bengal.

2.7 Index of biotic integrity (IBI)

A system's capacity to sustain and maintain a harmonious, adaptable, and integrated population of organisms during the course of natural development is referred to as its biological integrity. The term "integrity" suggests an undamaged condition, quality, or state of completion. The concept of "biotic integrity" is founded on the idea that the health of living things is the most accurate and direct indicator of the "integrity of water." The index of biological integrity (IBI) is a physically, chemically, and biologically quantifiable monitoring instrument that provides information on the overall health of a system by measuring the biological quality of surface water using fish community measures (Karr *et al*., 1986; Steedman, 1988). Therefore, it is crucial to monitor and evaluate the environmental status of numerous freshwater habitats using biological integrated assessment (Karr *et al*., 1986). Based on data from the individual, population, assemblage, and ecosystem levels, it was created as a numerical indicator and quality assessment for water bodies. Karr (1981) made the first suggestion, which Fausch *et al*. (1984) and Karr *et al*. (1986) later improved.

2.7.1 History of IBI development

The index, however first created for American streams, has now been tested in several other wetlands (Simon and Lyons, 1995), rivers, lakes, and estuaries outside of the United States and Canada (Hughes and Oberdroff, 1998; Toham and Teugels, 1999; Crettaz-Minaglia and Juarez, 2020; Flores-Lopes and Shilling, 2022) as well. Fish assemblages have also been widely used as indicators of ecosystem health. In India, Ganasan and Hughes (1998) in the Khan and Kshipra rivers in the country's central region, Abhijna and Kumar (2017) in lake Veli-Akkulam, South India, Das and Samanta (2006) in the freshwater zone of the Hooghly estuary, Haldar (2004) in two oxbow lakes in West Bengal, and Das *et al*. (2013) in the Ganga River have successfully assessed the IBI of their respective ecosystems using fish assemblages. Nevertheless, the application of IBI using fish assemblages in wetlands is scarce.

2.7.2 Fish as indicators of biotic integrity

The cumulative impacts of both natural and anthropogenic forces on the lake are reflected in the fish populations. While certain fish species need clean water and a pristine environment to exist, others may tolerate less than ideal circumstances. These species are regarded as "indicators" of the health of lakes. Fish communities serve as good indices of biotic integrity (Karr *et al*., 1986; Plafkin *et al*., 1989) because of the following characteristic features: they integrate the effects of complex and varied stressors on their prey, provide a relatively long-term record of environmental stress, integrate broad-scale habitat conditions, are relatively easy to identify to species, indicate the cumulative effects of multiple types of anthropogenic disturbances, their identification offers considerable additional information about their environments and they are of great interest to persons concerned about losses in biological diversity (Moyle and Leidy, 1992).

As a result, a better instrument for the quick evaluation and monitoring of the ecological status of these water bodies is required in order to build any relevant, comprehensive, ecologically sustainable, and scientific management strategy. Although there are many approaches based on the physical and chemical characteristics of water, employing biological communities to assess the state of water resources has gained importance recently (Miller *et al*., 1988; Karr, 1991; Paller, *et al*., 1996; Crettaz-Minaglia and Juarez, 2020; Flores-Lopes and Shilling, 2022). Studies on population dynamics, food web organisation, and community structure have been proven to be more accurate in foretelling the impact of numerous pressures on biological systems than single species bioassays (Schindler, 1987; Plafkin *et al*., 1989). An ecologically based metric for quantitatively evaluating the biological quality of surface waters is the index of biotic integrity (IBI) (Karr, 1981). It represents energy inputs, biological interactions, physical habitat quality, hydrological regime, land-water connections, and water quality (Karr *et al*., 1986; Steedman, 1988; Allan *et al*., 1997). Karr *et al*. (1986) modified the IBI to combine data from different levels (individual, population, assemblage, and ecosystem) into a single number or score and a rating for the quality of a body of water.

2.7.3 Development of the index of biotic integrity

As the IBI gained popularity, many modifications were recommended for vivid ecosystems and geographical areas such as estuaries, lakes, wetlands and taking account into regional variations in fish species. The IBI combines twelve fish assemblage attributes, or metrics, which could be broadly categorized into three groups: (i) species richness and composition; (ii) trophic composition; and (iii) fish abundance and health. The IBI was first proposed by Karr (1981) and later improved by Fausch *et al*. (1984) and Karr *et al*. (1986). The IBI score ranges from 12 to 60 and is the total of the twelve scores. Most of the original measures were mostly kept in the newer versions, although some were altered to increase their sensitivity to environmental deterioration in a specific area or kind of stream.

2.7.3.1 Species richness

Native species often decline as biological degradation increases, whereas increased abundance of non-native species is a sign of ecological deterioration. Determining native and non-native species in the metric, therefore, is crucial for determining ecosystem's health (Karr *et al*., 1986). An indicator of biodiversity at the family level that similarly declines with increased human disturbance is the number of native families (Noss, 1990). Additionally, Oberdorff and Hughes (1992) discovered that whole families became extinct in regions where humans had long-term, extensive habitation. Due to intense human influences, non-native groups often succeed better when native species are less abundant and predominate in severely disturbed water.

2.7.3.2 Habitat composition

Anthropogenic stress due to agricultural and urban development initially disturb the water chemistry, then ecological changes before vanishing the intolerant species and they are the slowest to emerge after restoration (Karr *et al*., 1986). It is also interesting to note that intolerant species are the first to reappear when the ecosystem starts to recover.

2.7.3.3 Trophic composition

The variety of a fish assemblage's eating patterns indicates the trophic composition and pattern, which provides more support for IBI. The trophic structure is determined by the proportion contributing to insectivore, piscivore, and omnivore populations (Karr *et al*., 1986).

2.7.3.4 Fish health and abundance

The total number of individual metrics directly reflects the lake's fish production. Fish anomaly metrics are often most helpful for bigger fish and in waterways that have been heavily contaminated by chemicals (Karr *et al*., 1986; Hughes and Gammon, 1987).

2.7.4 Development of an index of biotic integrity for Lakes

Hughes and Noss (1992) began assessment of potential metrics for an IBI for the lakes in the northeastern United States. The metrics showed a promising factor as indicators of biotic integrity and environmental quality for this lake. An effort was made to develop the IBI for Wisconsin lakes by Jennings *et al*. (1999). This index was based on species richness metrics (native species, centrarchid species, cyprinid species, intolerant species and small benthic species) and proportional (%) abundance metric (native benthic species, exotic fish, intolerant fish, tolerant fish, omnivores, top carnivores, lithophilic spawners and vegetation dwellers). Twelve metrics of three broad types: (i) species composition, (ii) trophic composition, and (iii) abundance and condition.

In contrast with lotic IBIs where diversity and abundance metrics have mostly been used, several biomass metrics were adopted in the Littoral Zone of Great Lakes' Areas by Minns *et al*. (1994). Schulz *et al*. (1999) examined the index of biotic integrity using eight fish assemblage metrics for estimating anthropogenic impacts to 60 Florida lakes ranging from 2 ha to more than 12,400 ha in size. Fish assemblage metrics tested were number of fish species, number of native fish species, *Lepomis* species, piscivore , generalist species, invertivore species, intolerant species and tolerant species. Lyons *et al*. (2000) studied lakes of central Mexico with effective 10 IBI metrics viz., number of total native species, common native species, native Goodeidae species, native *Chirostoma* species, native sensitive species, and maximum standard length of native species and lastly percent of exotic invertebrate parasite species in native fishes.

Haldar (2004) studied the index of biotic integrity for assessing the health status of two oxbow lakes (Bhomra *beel* and Mathura *beel*) in West Bengal by using twelve modified fish metrics. Multimetric index of index of biotic integrity using fish community was developed for the first time in lake Veli-Akkulam, South India by Abhijna and Kumar

(2017) by using seven candidate fish metrics such as native species richness, native family richness, benthic species richness, water column species richness, percentage non-native individuals, percentage tolerant individuals and percentage herbivores were applied in addition to five original metrics such as intolerant species richness, percentage omnivores individuals, percentage top carnivore individuals, total number of individuals and percentage individuals with anomalies.

2.8 Physico-chemical parameters of water

Water is a necessary conduit among several aspects that are crucial to wetland ecology, and the management and quality of water are key components of developments of aquatic organisms, disruption, abundance and an overall wetland conservation (Shah *et al*., 2015). The water quality of freshwater habitats, which is impacted by biological and physicochemical processes, offers trustworthy data on the state of the environment's resources (Bee *et al*., 2015). One of the main factors to determine the health of any water bodies is the combination of physical parameters such as water temperature, transparency, conductivity, and total dissolved solids (TDS) with chemical parameters such as pH, dissolved oxygen (DO), total alkalinity, hardness, nitrate-N (NO_3-N), and phosphate-P (PO_4-P) (Priyamvada *et al*., 2013). Any noticeable deviation from the acceptable limits has negative impacts on the physiological activities of living organisms. Each species has its own range of parameters within which they demonstrate optimal physiological activity (Kiran, 2010) including survival and growth. Therefore, continuous water monitoring is indispensable for improving the fish production (Bora and Biswas, 2015), for determining biological productivity and diversity of the ecosystem under consideration (Chowdhury, 2017).

2.8.1. Temperature

Temperature is the measure of heat or cold in an organism's body (Lucinda and Martin, 1999). Water temperature is one of the most influential key elements regulating not only the fish distribution (Mukherjee, 2011), survival, feeding (Adhikari, 2011), growth, metabolism and other physiological activities, but also productivity and several chemical and biological characteristics (Gupta, 2004; Bhatnagar and Devi, 2013). The most important determining elements for temperature are geography, climate, sun radiation, and water depth. Temperature below 16.7°C and above 39.5°C proves fatal to most fishes including carps (Jhingran, 1991). The water temperature ranging from 21.0°C to 35.5°C in the Baloon *beel*, 20.5°C to 31.5°C in Bhandaradaha *beel* in Murshidabad district; 26.2°C to 34.1°C in Baror *beel*, 24.5°C to 31.0°C in Bhomra *beel*, 26.2° to 34.1°C in Palda *beel* in Nadia district; 19.0° to 32°C in Ghurnamani *beel*, 20.5°C and 31.5°C in Haripur *beel* in Malda district; (Sugunan *et al*., 2000) has been recorded. Biswasroy *et al*. (2016) recorded an average water temperature of about 19.82°C in Mathura *beel*, Nadia district, West Bengal.

Temperature values varying from 20.47°C to 26.83°C (Purkayastha and Gupta, 2015) in Mona *beel*, 26.1°C and 28.0°C in Lake Baskandianua (Devi *et al*., 2016), 19.67±1.32°C and 28.67±0.5°C in Subansiri river basin, Lakhimpur (Gogoi *et al*., 2015) and, 10.0°C and 33.0°C in Borbilla *beel* (Deka *et al*., 2018) of Assam. Meena *et al*. (2019) observed that water temperature at Khalsi *beel* (a partially open wetland), Nadia, West Bengal ranged between 22.0 ±0.00 °C (winter) and 34.16±0.28°C (pre-monsoon) and in Akaipur *beel* (a closed wetland), North 24 Parganas ranged from 20.33±0.57 °C (winter) to 34±0.00 °C (pre- monsoon). Sarkar *et al*. (2020) reported water temperature at Bhomra *beel* (Nadia district), Mathura *beel* (North 24 Parganas) and Chandania *beel* (North 24 Parganas) in West Bengal ranging from 28.42±2.55°C to 29.93±3.60°C. Sarkar and Saha (2021) found temperature at Hasadanga *beel*, Nadia ranging from 20.2°C to 31.3°C, 20.0°C to 31.4°C and 20.9°C to 31.2°C during 2015, 2016 and 2017 respectively.

2.8.2 Transparency

Transparency, a property that changes depending on the interaction of colour and turbidity of water, is the amount of light that enters the water body generally measured by Scchi disc. The amount of sunshine, suspended soil particles, turbid water from the catchment region and plankton density are the chief factors that affect transparency levels (Mishra and Saksena, 1991; Singh, 1999; Nath and Srivastava, 2001). In general, transparency is lower in the monsoon seasons owing to the vast quantity of sediment delivered via the catchment region, respectively (Deorai, 1993). The value between 30 and 80 cm is good for fish growth. High suspended particles have an impact on fish productivity and also make it harder for fish to find food (Alabaster and Loyd, 1980). Sugunan *et al*. (2000) reported transparency ranging between 0.55 m and 1.65 m in lentic ecosystem of Baloon *beel* in Murshidabad district. In Bhandaradaha *beel* transparency ranged between 1.10 and 2.32 m. Whereas, Mondal *et al*. (2014) lower water transparency leves of about 21.5 cm in Ahiron *beel*, Murshidabad.

Laishram and Dey (2014), however, stated that transparency level was within 29-162 cm in Loktak Lake, Manipur, India. Similarly, Singh *et al*. (2017) studied that transparency in two floodplain Lakes, Gamhariachaur and Tarawechaur of north Bihar, India and reported the values from 9.9 cm to 63.8 cm. In the other reports, High transparency are generally associated with transition zone between high temperature and lesser temperature from May to June. Low transparency value is found due to stabilization of phytoplankton and zooplankton in the environment.

2.8.3 Total dissolved solids

Inorganic salts including calcium, magnesium, potassium, sodium, chlorides, sulphates, and others made up the majority of the total dissolved solids in the water, with very little organic stuff (Weber-Scannell and Duffy, 2007). Total dissolved solids (TDS) may be autochthonous or allochthonous in nature. Important allochthonic sources are mining, oil and gas drilling, or other industrial or municipal processes (Wetzel, 2001). It may change of chemical composition of water leading to mortality of aquatic organisms at times. Nonetheless, the majority of fish fauna can tolerate TDS values of 1000 mg/l (Boyd, 1998). Limnologists have observed temporal changes in TDS and found greater values in the pre-monsoon and lower values in the post-monsoon. Ganesan and Khan (2008) reported that the total dissolved solids in Purbasthali wetland in Burdwan district is 96.46 mg/l in pre-monsoon, 111.93 mg/l in monsoon and 126.28 mg/l in post-monsoon. Laishram and Dey (2014) reported TDS in the range of 50-150 mg/l in Loktak Lake, Manipur, India. Puthiyottil *et al*. (2021) studied that TDS ranged between 251.35±17.02 mg/l in Katiganga wetland and 563.62±41.90 mg/l in Bishnupur *beel*, Murshidabad district, West Bengal. Sarkar *et al*. (2020) found that the TDS ranged between 234.58±30.06 mg/l (Mathura *beel*) and 513.17±215.54 mg/l (Chandania *beel*) in West Bengal.

2.8.4 Water pH (Potential of hydrogen ion concentration)

The negative logarithm of the hydrogen ion concentration is referred as pH. It measures the concentration of H+ ions and the severity of water's acidity and alkalinity (Verma and Khan, 2015). It controls the majority of biological activities in water

(Sculthorpe, 1967). It is one of the most important chemical parameters to be monitored on day-to-day basis. Aquatic creatures are harmed by pH levels that are excessively low and high. A flourishing aquatic life is supported by a pH range of 6.7 to 8.4. (Dallas and Day, 2004). pH shows both spatial and temporal variations in aquatic ecosystem. Increase in pH levels might be because algae and other aquatic plants extract carbon dioxide from the water during photosynthesis Whereas, the stirring action of incoming water and an increase in microbial respiration, which releases carbon dioxide into the water, may be responsible for decrease in pH value. Some researchers noted the highest pH during the monsoon and the lowest during the pre-monsoon (Baruah and Sharma, 2013), while a few others noted high and low pH during the post-monsoon and the monsoon (Laskar and Gupta, 2009), and a few others noted the highest and lowest pH during the summer and the winter (Bordoloi *et al*., 2012).

Most of the *beels* in West Bengal are alkaline in nature and the reported range of pH is 8.2 to 9.8 (Sugunan *et al*., 2000; Mondal and Roy, 2014). Sarkar *et al*. (2020) found that the water pH ranged between 7.93±0.638 (Bhomra *beel*) and 8.86±0.614 (Mathura *beel*) in West Bengal. Puthiyottil *et al*. (2021) studied that water pH value in Katiganga wetland and in Bishnupur *beel*, Murshidabad district, West Bengal were 7.84±0.42 and 8.21±0.41 respectively. The mean water pH value ranged between 8.29 and 8.42 in Hasadanga *beel*, Nadia, West Bengal (Sarkar and Saha, 2021). Triparna *et al*. (2021) in Muragacha *beel*, North 24 Parganas, West Bengal observed pH range from 7.16±0.12 to 8.18±0.23.

2.8.5 Dissolved oxygen (DO)

One of the most vital factors in determining the quality of water and existence of aquatic organisms is the level of dissolved oxygen Dissolved oxygen influences physiology, distribution, behaviour, and resiliency (Solis, 1988). Its level, on the other hand is in turn influenced by temperature, plant density, and the presence of aquatic life (Moss, 1972; Kataria *et al*., 1996). Photosynthesis and respiration are the main phenomena for addition and reduction of oxygen in water. However, water also loses a significant amount of oxygen due to the decomposition of organic materials (Singh *et al*., 2017). Some organisms die when the amount of dissolved oxygen drops below 3 mg/l (Boyd, 1990), whereas the development of aquatic organisms is favoured by water that has more oxygen than 5 mg/l (McNeely *et al*., 1979).

Sugunan *et al*. (2000) reported that dissolved oxygen ranging from 5.47-6.48 mg/l in the Baloon *beel* in Murshidabad district and 4.61-13.0 mg/l in Bhandaradaha *beel* of West Bengal. According to Mondal and Roy (2014) dissolved oxygen of the Ahiron Lake was 9.35 mg /l. A wide range of DO (2.4-10.2 mg/l) in chaurs of Bihar has been reported (Pankaj *et al*., 2017; Singh *et al*., 2017). The DO values were found in the range of 3.19–9.18 mg/l in Loktak Lake, India. The lowest DO was observed during the monsoon and the highest was recorded during winter (Kangabam *et al*., 2017). During summer season dissolved oxygen concentration were recorded minimum, whereas maximum dissolved oxygen were recorded during winter season (Ranjith *et al*., 2017; Verma *et al*., 2018). Sarkar *et al*. (2020) found that the dissolved oxygen ranged between 7.71±2.00 mg/l (Bhomra *beel*) and 8.29±2.24 mg/l (Chandania *beel*) in West Bengal. Puthiyottil *et al*. (2021) studied that dissolved oxygen value in Katiganga wetland and in Bishnupur *beel*, Murshidabad district, West Bengal were 5.67±1.20 mg/l and 6.04±0.99 mg/l, respectively. The mean dissolved oxygen value ranged between 4.27 mg/l and 4.87 mg/l in Hasadanga *beel*, Nadia, West Bengal (Sarkar and Saha, 2021). Triparna *et al*. (2021) in Muragacha *beel*, North 24 Parganas, West Bengal observed dissolved oxygen range from 5.32±0.78 mg/l to 8.29±0.58 mg/l.

2.8.6 Free carbon dioxide

Free carbon dioxide is the end product of organic carbon degradation in aquatic environment and its variation is often a measure of net ecosystem metabolism. It is also used as a key parameter in evaluation of pollution (Hopkinson, 1985). Carbon dioxide is also the most important greenhouse gas on earth. Its fluxes across the air-water or sediment water interface are among the most important concerns in global change studies (Patil *et al*., 2012). According to Ekubo and Abowei (2011) tropical fishes can tolerate carbon dioxide levels over 10 mg/l but the ideal level of carbon dioxide in fishpond is less than 10 mg/l. When dissolved in water it forms carbonic acid which decreases the pH of any system, especially insufficiently buffered systems, and this pH drop can be harmful for aquatic organisms. The value of carbon dioxide fluctuate widely due to its capacity to combine with different cations (Ca^{++}, Na^{++}, K^{+}).

The free carbon dioxide in water supporting good fish population should be less than 5 mg/l (Santhosh and Singh, 2007). According to Boyd and Lichtkoppler (1979) fish avoid free carbon dioxide levels as low as 5 mg/l but most species can survive in waters containing upto 60 mg/l carbon dioxide. Bhatnagar *et al*. (2004) suggested 5-8 mg/l is essential for photosynthetic activity.

Sarkar *et al*. (2020) found that the free carbon dioxide ranged between 5.238±0.044 mg/l (Bhomra *beel*) and 7.42±3.363 mg/l (Chandania *beel*) in West Bengal. The mean free carbon dioxide value ranged between 0 and 5 mg/l in Hasadanga *beel*, Nadia, West Bengal (Sarkar and Saha, 2021). Triparna *et al*. (2021) in Muragacha *beel*, North 24 Parganas, West Bengal observed free carbon dioxide range from 2.6±1.39 to 8.46±3.01 mg/l.

2.8.7 Hardness

The general indicator of water type, buffering power, and productivity is hardness. Water hardness is caused by calcium and magnesium compounds, which may be found chiefly as carbonates, sulphates and chlorides (Prakash, 1997). It is measured in milligram of equivalent calcium and magnesium per litre (Sharma, 2000). According to equivalent $CaCO_3$ content, the degree of hardness of freshwater resources has been categorised as follows: Soft: 0–60 mg/l, Medium: 60–120 mg/l, Hard: 120–180 mg/l, and very hard: > 108 mg/l (Dohare *et al*., 2014). The sum of the water's transient and permanent hardness is its total hardness. Temporary hardness in water is caused by the bicarbonates of calcium and magnesium ions, but permanent hardness in water is caused by chlorides and sulphates (Upadhyay and Chandrakala, 2016).

Sugunan *et al*. (2000) recorded that the hardness value of 79.0-124.4 mg/l in Baloon *beel* and 119.0-194.4 mg/l in the Bhandaradaha *beel*. Mondal and Roy (2014) noticed hardness of the Ahiron *beel* as 142 mg/l. Umerfaruq and Solanki (2015) opined that increased amount of total hardness in the water was due to the presence of high content of calcium and magnesium ions in addition to sulphate and nitrate in the sewage waste added during monsoon. Kumari and Sharma (2018), however, recorded maximum total hardness in summer season owing to higher temperature, resulting in the increased concentration of salts by excessive evaporation. Sarkar *et al*. (2020) found that the total hardness in water ranged between 155.25±41.93 mg/l (Mathura *beel*) and 245.12±58.50 mg/l (Chandania *beel*) in West Bengal. The mean hardness value ranged between 115 mg/l and 142 mg/l in Hasadanga *beel*, Nadia, West Bengal (Sarkar and Saha, 2021). Triparna *et al*. (2021) in Muragacha *beel*, North 24 Parganas, West Bengal observed hardness range from 125±6.64 to 144±24.5 mg/l.

2.8.8 Alkalinity

Alkalinity, a measurement of the total concentration of bases in pond water including carbonates, bicarbonates, hydroxides, phosphates, and borates, dissolved calcium, magnesium, and other compounds in the water, is the water's capacity to withstand variations in pH (Stumn and Morgan, 1981). It measures ability to act as a buffer, is crucial for aquatic life in fresh water systems (Baniyan *et al*., 2019). Total alkalinity is a measurement of a liquid's receptivity to acidic inputs as well as its capacity to neutralise acidic waste water contamination. Alkalinity is increased by lime leaching from calcareous rocks, photosynthesis, denitrification, and sulphate reduction, while it is also, to a lesser extent, increased by evaporation and decomposing organic matter (Patil *et al*., 2018); while respiration, nitrification, and sulphide oxidation are some of the factors responsible decrease of alkalinity.

Sugunan *et al*. (2000) recorded alkalinity range from 115.2 mg/l to 177.6 mg/l in the Baloon *beel* and 129.0 mg/ l to 220.8 mg/l. in the Bhandaradaha *beel* of West Bengal. Mondal and Roy (2014) investigated that the alkalinity of water is 3 mg/l in Ahiron *beel*. Sarkar *et al*. (2020) found that the alkalinity ranged between 173.76±58.56 mg/l (Chandania *beel*) and 198.41±1.38 mg/l (Bhomra *beel*) in West Bengal. Puthiyottil *et al*. (2021) studied that alkalinity value in Katiganga wetland and in Bishnupur *beel*, Murshidabad district, West Bengal were 146.12±37.30 mg/l and 249.78±35.45 mg/l respectively. The mean alkalinity value ranged between 175 and 189 mg/l in Hasadanga *beel*, Nadia, West Bengal (Sarkar and Saha, 2021). Triparna *et al*. (2021) in Muragacha *beel*, North 24 Parganas, West Bengal observed alkalinity range from 159±7.6 to 178±17.18 mg/l.

2.8.9 Nitrate-nitrogen (NO_3-N)

Nitrogen is present as nitrate in natural water. Development of photosynthetic autotrophs is regulated by the presence of nitrates. The main source of nitrate into the aquatic system is nitrifying bacteria's activity and agricultural nitrogen. Continuous rise in nitrate content is hazardous as it promotes the establishment of algal blooms, leading to oxygen depletion and mortality of fishes. It is crucial in determining the productivity of aquatic ecosystems and speeds up the development of macrophytes and algae. Due to human activities including food production, agriculture and manure management, as well as the discharge of home and industrial waste, nitrate is present in water from a variety of natural sources (Lodh *et al.*, 2014).

Bheemappa *et al*. (2015) documented the higher concentration of nitrate-nitrogen during winter season and the low concentration during monsoon season. Javeed *et al*. (2019) observed higher values of nitrate during winter that could be due to reduced metabolic activities because of less plant cover while minimum values during summer could be due to its assimilation by plant growth. Sarkar *et al*. (2020) found that nitrate-nitrogen ranged between 0.06±0.04 mg/l (Chandania *beel*) and 0.11±0.04 mg/l (Mathura *beel*) in West Bengal. Puthiyottil *et al*. (2021) studied that nitrate-nitrogen value in Katiganga wetland and in Bishnupur *beel*. Murshidabad district, West Bengal were 0.14±0.09 mg/l and 0.26±0.14 mg/l respectively. Triparna *et al*. (2021) in Muragacha *beel*, North 24 Parganas, West Bengal observed nitrate-nitrogen range from 0.21±0.02 mg/l to 0.3±0.09 mg/l.

2.8.10 Phosphate-phosphorus (PO_4-P)

Phosphate mainly occurs in the form of orthophosphates and is the most critical factor in maintaining aquatic ecosystem. Favourable growth response of plankton population was observed at the time of higher concentration of phosphates in pond water. Manna (2008) explained that phosphorus is often considered to be the most critical single element in the maintenance of aquatic productivity and its fertility ranging from 0.05 to 0.20 mg/l. In tropical waters due to high temperature, phosphate rapidly assimilates (95% within 20 minute) by plankton and micro-organisms and hence available phosphate concentration is very low (Hayes and Phillips, 1958). The role of phosphorus as a limiting factor in the production of algae in natural lakes is diverse and complicated (Welch, 1952).

The phosphate value range from 0.2 to 0.4 mg/l in Chupi char located in Burdwan district of West Bengal (Biswasroy *et al.*, 2016). Sugunan *et al*. (2000) reported that the phosphate-phopshorus range from 0.03 to 0.08 mg/l in the Baloon *beel* in Murshidabad district. Sarkar *et al*. (2020) found that phosphate-phosphorus ranged between 0.029±55.02 mg/l (Bhomra *beel*) and 0.08±0.10 mg/l (Chandania *beel*) in West Bengal. Puthiyottil *et al*. (2021) studied that phosphate-phosphorus value in Katiganga wetland and in Bishnupur *beel*, Murshidabad district, West Bengal were 0.05±0.02 mg/l and 0.28±0.12 mg/l respectively. Triparna *et al*. (2021) in Muragacha *beel*, North 24 Parganas, West Bengal observed phosphate-phosphorus range from 0.59±0.06 mg/l to 0.71±0.2 mg/l.

Table 2.2. Range of physico-chemical water quality parameters in floodplain wetlands of West Bengal reported by various authors are summarized

Floodplain wetlands	Findings	Source of data
Water temperature		
Santragachi Jheel	27.58±3.29° C	Patra *et al*. (2010)
Gajoldoba *beel* and Domohani *beel*, Jalpaiguri district	25.98ºC	Datta (2011)
Mathura *beel*	19.82 ºC	Biswasroy *et al*. (2011)
Suguna *beel* and kole *beel*	26.3±0.85 ºC - 27.34±0.83ºC	Ziauddin *et al*. (2013)
Kalyani Lake	27.03ºC - 32.03ºC.	Panigrahi *et al*. (2014)
Panishala *Beel* at Cooch Behar	18.6 ºC	Pal *et al*. (2015)
Sagardighi of Cooch Behar	28.58°C - 29.83°C	Miraj and Bhattacharya (2017)
Bhara Haripota *beel* in Bhamanghata	20.6 ºC - 31.0 ºC	Singh *et al*. (2017)
Chhariganga oxbow lake in Nadia district	27.64±6.56 ºC	Ghosh and Biswas (2018)
Hasadanga *beel*, in Nadia district	20.0±0.04 ºC to 31.4±0.01 ºC	Sarkar and Saha (2021)
Muragacha *beel*, North 24 Parganas district	20.2 – 32.8 ºC	Triparna *et al*. (2021)
Transparency		
Santragachi Jheel	56.42±8.58 cm	Patra *et al*. (2010)

Gajoldoba *beel* and Domohani *beel*, Jalpaiguri district	31 to 33 cm	Datta (2011)
Suguna *beel* and Kole *beel*,	1.94±0.05 m to 1.34±0.02 m	Ziauddin *et al*. (2013)
Bhara Haripota *beel* in Bhamanghata, South 24 Parganas district	18.6 to 26.5 cm	Singh *et al*. (2017)
Chhariganga oxbow lake in Nadia district	45.82±23.39 cm	Ghosh and Biswas (2018)
Akaipur wetland, North 24 Parganas and Khalsi wetland, Nadia district	0.21±0.01 to 0.75±0.02 m and 0.483±0.035 to 1.14±0.05 m	Meena *et al*. (2019)
Katiganga & Bishnupur in murshidabad district	1.3±0.29 m, 0.65±0.35 m	Puthiyottil *et al*. (2021)
Total dissolved solids		
Santragachi Jheel	569.38±75.39 mg/l	Patra *et al*. (2010)
Joypur Jheel	121.80 mg/l - 332.39 mg/l	Patra *et al*. (2010)
Sagardighi of Cooch Behar	22 mg/l to 271 mg/l	Miraj and Bhattacharya (2017)
Katiganga & Bishnupur in Murshidabad district	251.35±17.02 mg/l563.62±41.90 mg/l	Puthiyottil *et al*. (2021)
Water pH		
Gajoldoba *beel* and Domohani *beel*, Jalpaiguri district	7.2	Datta (2011)
Mathura *beel*,	7.3	Biswasroy *et al*. (2011)
Suguna *beel* and kole *beel*, West Bengal, India	7.99 - 7.94	Ziauddin *et al*. (2013)
Kalyani Lake	7.16 - 8.37	Panigrahi *et al*. (2014)
Panishala *Beel* at Cooch Behar	6.80	Pal *et al*. (2015)

Sagardighi of Cooch Behar	6.63 - 9.54 during 2011-16	Miraj and Bhattacharya (2017)
Bhara Haripota *beel* in Bhamanghata, South 24 Parganas district	7.2 to 8.2	Singh *et al*. (2017)
Chhariganga oxbow lake in Nadia district	8.17	Ghosh and Biswas (2018)
Dissolved oxygen		
Santragachi Jheel	6.04±1.59 mg/l	Patra *et al*. (2010)
Bhara Haripota *beel* in Bhamanghata, South 24 Parganas district	4.18 - 5.76 mg/l	Singh *et al*. (2017)
Sagardighi of Cooch Behar	5.2 mg/l - 9.9 mg/l	Miraj and Bhattacharya (2017)
Chhariganga oxbow lake in Nadia district	4.65±1.52 mg/l	Ghosh and Biswas (2018)
Total alkalinity		
Suguna *beel* and Kole *beel*,	117.98±5.38 mg/l - 177.99± 4.23 mg/l	Ziauddin *et al*. (2013)
Kalyani Lake	27.05 mg/l - 53.58 mg/l	Panigrahi *et al*. (2014)
Mathura Lake	111 ± 30 mg/l	Bhattacharya (2015)
Sagardighi of Cooch Behar	15.2 mg/l - 68mg/l	Miraj and Bhattacharya (2017)
Chhariganga oxbow lake in Nadia district	Mean value 120±24.03 mg/l	Ghosh and Biswas (2018)
Hardness		
Suguna *beel* and Kole *beel*,	152.8 mg/l to 198.3 mg/l	Ziauddin *et al*. (2013)
Mathura Lake	118 ± 27 mg/l	Bhattacharya (2015)
Chhariganga oxbow lake in Nadia district	102.62±19.60 mg/l	Ghosh and Biswas (2018)

Free carbon dioxide		
Bhomra *beel* and Chandania *beel*	5.238±0.044 mg/l and 7.42±3.363 mg/l	Sarkar *et al*. (2020)
Hasadanga *beel*	0 – 5 mg/l	Sarkar and Saha (2021)
Muragacha *beel*	2.6±1.39 – 8.46±3.01	Triparna *et al*. (2021)
Nitrate-nitrogen		
Suguna *beel* and Kole *beel*	0.06±0.00009 mg/l - 0.133±0.0069 mg/l	Ziauddin *et al*. (2013)
Mathura Lake	0.27 ± 0.09 mg/l	Bhattacharya (2015)
Chhariganga oxbow lake in Nadia district	0.81±0.69 mg/l	Ghosh and Biswas (2018)
Phosphate-phosphorus		
Suguna *beel* and kole *beel*,	0.036 ± 0.001 mg/l - 0.036±0.002 mg/l	Ziauddin *et al*. (2013)
Mathura Lake	0.21 ± 0.10 mg/l	Bhattacharya (2015)
Kalyani Lake	0.20 mg/l to 0.63 mg/l	Panigrahi *et al*. (2014)
Muragacha *beel*	0.59±0.06 – 0.71±0.2 mg/l	Triparna *et al*. (2021)

2.9 Physico-chemical characteristics of sediment

2.9.1 Importance of soil quality

In aquatic ecosystem, soil is the primary source of the many nutrients needed for the development of aquatic plants. Understanding the soil's function in *beel* production in connection to fisheries depends on factors like its texture, reactivity, oxygen tension, quality and amount of organic matter, soil pH, soil nutrient mineralization capacity, etc. There is mounting evidence that water quality is significantly influenced by the health of *beel* bottoms and the exchange of chemicals between soil and water (Boyd and Clay, 1998). More or less reflecting the characteristics of bottom soil are the chemical characteristics of water in *beels* (Chandra, 1997).

The soil in the basin of the floodplain wetlands has less sand as a proportion. Sand, silt, and clay concentration (%) in West Bengal's Bhomra and Haripur (open) *beels* are 65, 21, 14, and 50, 11, 39, respectively. Sugunan *et al.* (2000) reported that the soils of floodplain wetland areas are enriched in organic matter, inorganic minerals, silt, and clay. Since aquatic vegetation dominates the majority of the floodplain wetlands, there is a significant buildup of dead plant material at the bottom that decomposes.

2.9.1.1 Soil pH

Soil pH at neutral range (pH 6.5 to 7.5) is considered to be most ideal for fish culture. While soil pH influences the water pH but itself is influenced by various factors (Adhikari, 2011). When the mud layers are not well aerated and the supply of oxygen falls short then the decomposition rate of the products is reduced or partially oxidized. Sugunan *et al*. (2000) reported that the soil pH in Baloon *beel* in Murshidabad was ranging from 6.28 to 7.0. Chatterjee *et al*. (2014) recorded the soil pH ranging between 6.9 and 7.3. According to Palit and Mukherjee (2011) soil pH ranged from 5.99 to 6.55 in Lalbandh wetland, Birbhum district, West Bengal. Mohan *et al*. (2020) reported soil pH was ranging from 7.30±0.10 to 8.17±0.12 in Nalban wetland of East Kolkata wetlands, West Bengal. Ziauddin *et al.* (2013) observed soil pH was ranging from 6.0 to 7.0, indicated of high productivity in the Saguna *beel* (closed), Nadia district and Kole *beel* (open), in Hooghly district, West Bengal.

2.9.1.2 Organic carbon

For bacteria and other microorganisms that release nutrients via different biochemical processes, organic carbon serves as a source of energy (Adhikari, 2011). Less than 0.5% of organic carbon is regarded as unproductive, 0.5-1.5% as medium-productive, and 1.5-2.5% as very productive in nature (Boyd and Ayub, 1994; Ahmed, 2004 and Adhikari, 2011). Wetlands tend to collect organic matter, which makes soil darker, due to an imbalance between primary production and breakdown (Mausbach and Richardson, 1994).

Wetlands get organic materials from both internal and external sources. The dead sections of macrophytes, detritus from algal and microbial mats, and the underground portion, such as roots and rhizomes, are among the internal sources (Reddy and Delaune, 2008). Sugunan *et al*. (2000) reported soil organic carbon ranging from 0.10 % to 1.46 % in the Baloon *beel*, Murshidabad district. Generally, higher organic carbon contents (0.10-7.85%) were recorded in the closed and weed choked *beels* indicating high organic production in the water bodies. Closed but moderately weed infested *beels* had comparatively lower organic carbon contents (0.12-5.99 %), while open (moderately weed infested) *beels* recorded still lower values (0.10-2.31%). Adhikari *et al*. (2020) reported that the soil organic carbon in some wetlands namely, Purbasthali, Raichenmari, Bochamari, Atiamochar, Nararthali and Lalbandh in West Bengal was ranging from 19.56 t/ha to 53.34 t/ha.

2.9.1.3 C/N ratio

Nitrogen, being a basic and primary constituent of protein, is required to stimulate primary production in aquatic environments and is essential for the formation of living matter. In soils nitrogen occurs almost entirely in organic form which is gradually mineralized to soluble inorganic nitrogenous compounds (NH_4, NO_3, NO_2) by obligate as well as facultative anaerobes and subsequently utilized by fish food organisms. The organic matter in wetland soil is not only an important source of surface soil organic carbon, but also an important indicator for judging the soil fertility of wetlands (Nadi *et al*., 2017). Nitrogen is the most important limiting nutrient in wetland soils and a sensitive indicator for measuring the soil nutrient levels in wetlands (Ma *et al*., 2016). The carbon in the wetland soil is mainly produced by plants that fix the carbon in the atmosphere through photosynthesis, and it is an important factor that affects greenhouse gas emissions (Jauss *et al*., 2017). Therefore, determining the contents of soil organic carbon, total nitrogen in wetland soil is of great significance for protecting the wetland ecological environment (Lu *et al*., 2018). The C/N ratio is a useful tool to assess the nature of organic matter (Vishwas *et al*., 2009). The low C/N values indicate the presence of relatively fresh organic matter derived from bacteria and microalgae. In contrast, high C/N ratio in indicates the presence of degraded organic matter and/or the influence of terrestrial organic matter (Vishwas *et al*., 2009). Banerjea (1967) opined that the C/N ratio less than 5 as very poorly productive; in the range 5 to 10 as productive and between 10 and 15 ideal for aquatic systems.

Sugunan *et al*. (2000) reported that, Bhomra recorded the highest values of organic carbon (3.72-7.85%), total nitrogen (0.09-0.63%) and C:N ratio (14.44). Comparatively higher average C: N ratio (9.7-20.3) recorded in closed *beel* than those of open ones (8.00-13.83). Bhaumik *et al*. (2006) reported that in summer and winter highest C:N ratio (12-14) were seen in Suguna and Amda *beel*.

2.10 Plankton

Plankton is one of the best indicators of water quality (Pradhan *et al*., 2008) and biological productivity of aquatic habitat (Saksena, 1987). Plankton are the main source of food for various fishes and other aquatic organism. The term plankton includes generally microscopic aquatic flora (phytoplankton) and fauna (zooplankton) having limited power of locomotion and drifted by water currents. Phytoplankters are primary producers which form the base of the autotrophic food chain (Saravanakumar *et al*., 2008). Zooplankters convert plant and organic matter into animal matter and form an important link in both the autotrophic and heterotrophic food chains. Thus, plankton sustains planktophagous and predatory fish populations in *beel* ecosystem either directly or indirectly (Shil *et al*., 2013). The stagnant floodplain waters are one-of-a-kind environments in terms of water chemistry, phytoplankton and zooplankton composition, and dynamics, with exceptional spatial and temporal heterogeneity in the ecosystem, resulting in high species and population richness (Pithart, 1999).

Generally, population of phytoplankton and zooplankton in the floodplain wetlands is low during the southwest monsoon season and increases thereafter when the environment becomes stable and the plankton population establishes utilizing inorganic nutrients and organic matter brought in by the incoming flood or run-off waters (Sugunan *et al*., 2000).

2.10.1 Phytoplankton

Phytoplankton forms the base for life of an ecosystem. They are often regarded as indicators of overall health of an ecosystem because of their sensitivity and changes in species composition (Gaikwad *et al*., 2004). Phytoplankton is the most pervasive, single-celled, and tiny living form in an aquatic environment. In aquatic environments, phytoplankton is crucial because it produces food and oxygen that support all other living forms and maintains ecological equilibrium (Elayaraj *et al*., 2016). Any change in the phytoplankton community structure not only affects the productivity of aquatic systems but also alters the food chain. The succession of phytoplankton is associated with variations in ambient abiotic factors including temperature, light, and nutrition availability (Jain *et al*., 2018). Further, several phytoplankton species recognised as indicators of aquatic pollution, hence form an important group for biomonitoring in lentic freshwater systems. According to Annalakshmi and Amsath (2012), phytoplankton is essential for maintaining the balance between the biotic and abiotic elements of an aquatic environment. According to Goldman and Horne (1983), the phytoplankton has a significant impact on the dynamic characteristics of lakes, including colour, clarity, trophic status, zooplankton, and fish productivity (Hulyal and Kaliwal, 2009).

Sugunan *et al*. (2000) reported that Seventy four species of phytoplankton in West Bengal *beels*, which include 23 diatoms, 20 green algae, seven blue green algae and four others. *Synedra ulna* and *Melosira granulosa* (diatoms) constituted the bulk of the winter peak plankton population while the blue-green algae species *Microcystis aeruginosa* dominated the summer peak population in Bhandardaha *beel* (open *beel* in Gangetic basin). *Microspora, Eudorina, Volvox* and *Pleodorina* were commonly observed green algae whereas the groups Eugleninae and dinoflagellates were represented by *Phacus* and *Ceratium,* respectively. The group *Chlorophyceae* and *Bacillariophyceae* dominated the plankton population in most weed choked (closed) *beels*. It is possible that dominance of these two groups in these *beels* is facilitated by the rapid removal of plant nutrients by macrophytes from soil and water. In contrast, most moderately weed infested *beels* (both closed and open types) showed the dominance of Cyanophyceae. According to Sugunan *et al*. (2000) availability of phytoplanktons in the West Bengal *beels* ranged from 396-14987 u/l (mean value: 1188-11203 u/l). Rout *et al*. (2010) reported the phytoplanktons density ranged between 506 nos/l and 734 nos/l in Mathura *beel* spreading across the district of Nadia and North 24 parganas, West Bengal. Keshri *et al*. (2013) reported the phytoplankton density was highest in post-monsoon (12633/l) followed by monsoon (10500/l) and pre -monsoon (7266/l) in Baishar *beel*, Nadia district, West Bengal.

Table 2.3 Phytoplankton diversity of various floodplain wetlands of West Bengal

Locality	Phytoplankton	Source
Two large oxbow wetlands, situated in the district of North 24 Parganas	A total of 43 taxa of phytoplankton belonging mainly to families Myxophyceae (7 taxa), Chlorophyceae (17 taxa) and Bacillariophyceae (12 taxa)	Khan (2002)
Suguna *beel* and Amda *beel*	1,346 and 2,170 units/l in Suguna *beel* whereas in Amda bed it ranged from 1,030 to 1,802 units/l	Bhaumik *et al*. (2006)
Mathura *beel* in the districts of Nadia and 24 Parganas (N)	22 species of phytoplankton belonging to Chlorophyceae (8), Cyanophyceae (6), Baillariophyceae (7) and Englenphyceae (1)	Rout *et al*. (2010)
Baishar*beel* of the Nadia district	30 species of phytoplankton of 4 distinct classes, Chlorophyceae (14), Cyanophyceae (9), Bacillariophyceae (5) and Euglenophyceae (2)	Keshri *et al*. (2013)
Mathura *Beel*, a Floodplain wetland	96 species belonging to 87 genera six algal classes.	Maiti *et al*. (2014)
Bhara Haripota *beel* in Bhamanghata, South 24 Parganas district	Chlorophyceae and Cyanophyceae are dominant phytoplankton groups	Singh *et al*. (2017)

2.11 Macrophyte diversity

In contrast to phytoplankton, aquatic macrophytes are macroscopic plants which commonly include macroalgae, mosses, ferns, and angiosperms that are found in aquatic environment. The most significant biotic element of the littoral zone of the lake ecosystem is represented by aquatic macrophytes. One of the most conspicuous features of a typical wetland or a *beel* is the presence of diverse macrophytes. Depending on their habitat, macrophytes are categorized free-floating, emergent, submerged, and other living forms. They have come from many different groups and often exhibit extraordinary flexibility in their morphology and structure in response to shifting environmental circumstances. Macrophytes may be used as a technique to assess trophic status, water quality, lake state, and nutrient levels (Arya *et al*., 2018).

Macrophytes serve a variety of functions in the design and operation of wetland ecosystems. In addition to providing shelter and food for aquatic life, macrophytes are regarded as an essential aspect of the aquatic environment because they are effective heavy metal accumulators and take part in the water's natural processes of self-purification (Sharma and Singh, 2017). Aquatic macro-vegetation was thought to have a significant impact in recycling nutrients thereby, keeping the ecological equilibrium in check. Some aquatic plant species have been recognised as pollution indicators too. According to Varshney (1981), several aquatic plants, including *Lemna*, *Eichhornia*, *Utricularia*, *Myriophyllum*, *Nuphar*, and *Potamogeton*, may serve as indicators of pollution.

Das *et al*. (2009) reported Altogether 13 genera of aquatic macrophytes belonging to 10 families, and 24 plant species (bank flora) belonging to 16 families in the Hansadanga *beel*, Nowapara *beel* and Kaji *beel* Krishnagar city, West Bengal, India. Some authors also observed seasonal variations in abundance of macrophytes. Ghosh and Biswas (2015) examined among emergent, *Cynodon* sp was the most dominant during pre-monsoon and post-monsoon and *Ipomoea* sp during monsoon. Among the free-floating genus, *Eichhornia* sp was highly dominant throughout the year while *Lemna* sp topped the group during pre-monsoon. Among the submerged genus, *Hydrilla* sp was observed to be the most dominant genus throughout the year. Among rooted floating-leaved *Nymphaea* sp was highly dominant during monsoon and post-monsoon and *Brasenia* sp during pre-monsoon.

2.12 Carlson’s Trophic State Index (CTSI)

A prominent approach for describing the trophic condition or general health of a lake is Carlson's Trophic State Index (CTSI) which makes use of measurements for phosphorus, chlorophyll a, and Secchi's disc transparency. The Carlson's trophic status index was be calculated using the average values of these three parameters' TSI (Carlson, 1977). Secchi disc (SD) depth is the simplest method for measuring TSI, which has a high correlation with the biomass and yearly production of suspended algae (Pechkam *et al*., 2006). Because total phosphorus (TP) being a limiting element in aquatic environments, its rise in aquatic ecosystem may be responsible for changes in the trophic status of a lake (Soeyink and Jenkins, 1980). But among the three variables, chlorophyll a is given more importance for categorization since it is the most reliable indicator of algal biomass (Hakanson and Boulion, 2001). The Carlson Trophic State Index (TSI) (Carlson, 1977) was used to determine the trophic state classification based on the following criteria.

Patra *et al*. (2016) studied trophic state index of Nalban Lake of East Kolkata Wetland which indicates that the lake is appeared to be eutrophic to hyper eutrophic conditions. Puthiyottil *et al*. (2021) reported that the values of CTSI of Katiganga, an open *beel* in Gangetic basin, ranged from 50 to 55.

Table 2.4 Trophic state classifications based on Carlson TSI (Carlson, 1977)

Classification	Description	Sub-classification	Trophic state index
Oligotrophic	Clear water, dissolved oxygen throughout the year in the hypolimnion.	Strongly oligotrophic	0-25
	Deep lakes still exhibit classical oligotrophy, but some shallower lakes become anoxic in the hypolimnion during the summer.	Oligotrophic	26-32
		Slightly oligotrophic	33-37
Mesotrophic	Water moderately clear, but increasing probability of anoxic in hypolimnion during summer.	Slightly mesotrophic	38-42
		Mesotrophic	43-48
		Strongly mesotrophic	49-53
Eutrophic	Lower boundary of classical eutrophic; decreased transparency, anoxic hypolimnion during the summer, macrophyte problems evident and warm-water fisheries only.	Slightly eutrophic	54-57
		Eutrophic	58-61
	Dominance of blue-green algae, algal scum probable, extensive macrophyte problems	Strongly eutrophic	62-64
Hyper-eutrophic	Heavy algal blooms possible throughout the summer, dense macrophyte beds, but extent limited light penetration	Hyper-eutrophic	65+

(Melcher, 2013)

Chapter 3

MATERIALS AND METHODS

3. MATERIALS AND METHODS

3.1 Study area

3.1.1 Geographical location

West Bengal, the only state (Map 1) of India that extends from the Himalayas in the North to the Bay of Bengal in the south, located between Latitude 21°38’ N to 27°10’ N and Longitude 85°38’ E to 89°50’ E. Bansabati beel (24°27' 13" to 24°29' 25" N and 87°59' 22" to 88°01' 19"E), an open wetland situated at the margin of Suti-I and Raghunathganj-I Blocks of Murshidabad district (Map 1), West Bengal, India, was chosen purposively for the present investigation.

3.1.2 Brief description of Bansabati beel

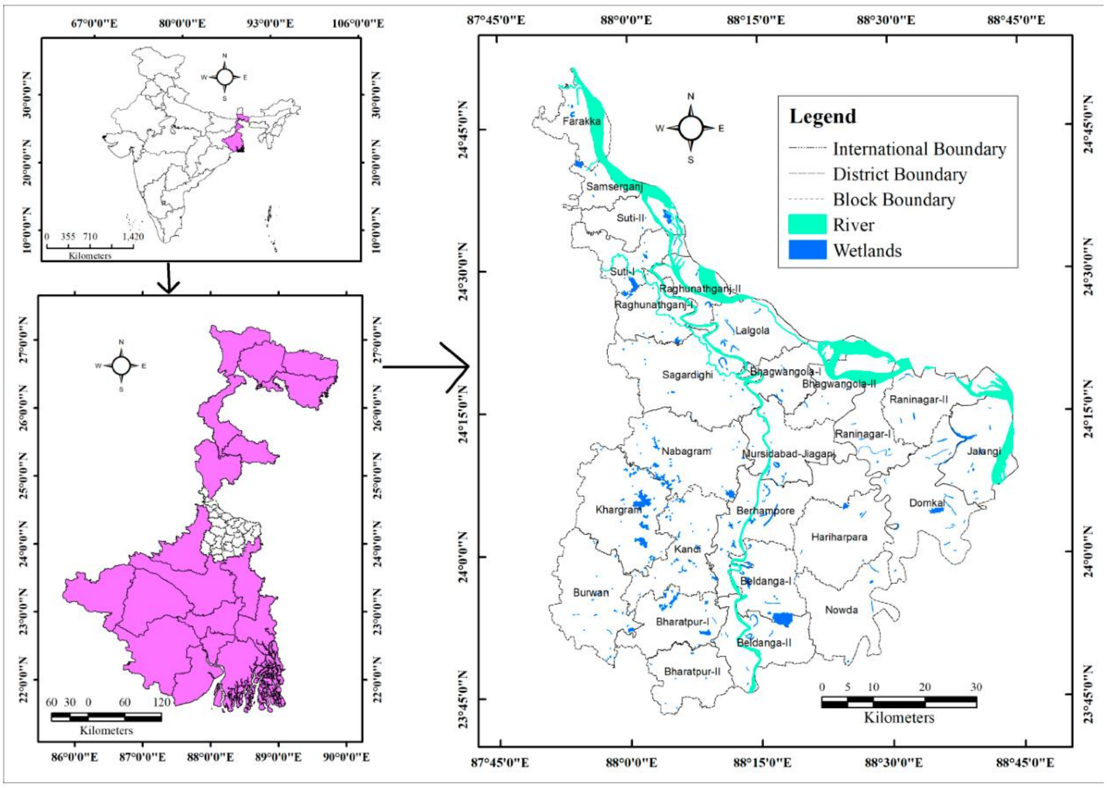
Bansabati beel (Figure 1) is classified as a riverine wetland because it occurs in the riverine floodplain of the Ganga-Bhagirathi River system. Bansloi and Pagla, two small and low-gradient streams that originate in the Chotonagpur plateau's Santhal-Pargana highland, drain into the beel (Mondal, 2012). The beel’s hydrological behaviour is complex, with total inundation during the monsoon and partial drying during the pre-monsoon, resulting in water shrinkage (Pal and Akoma, 2009). The beel is vulnerable to agricultural run-off from nearby agriculture fields as well as land filling activities surrounding it. Table 3.1 shows the general morphometric characteristics of the Bansabati beel.

3.2 Sampling site selection

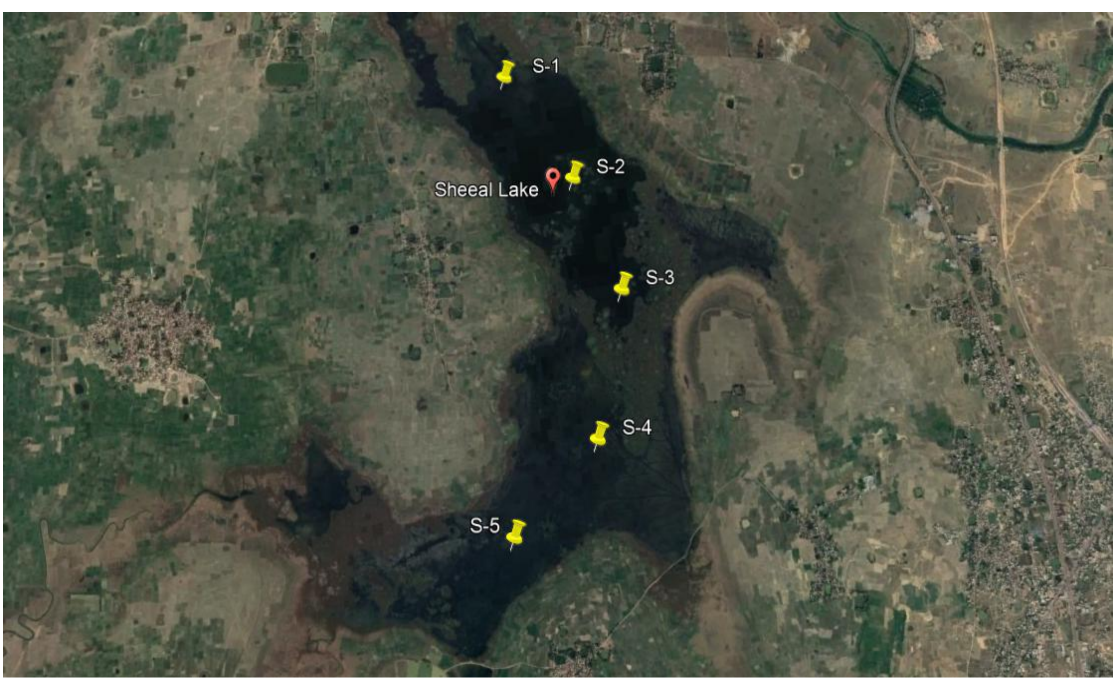
Five sampling stations namely, Station 1 (S1), Station 2 (S2), Station 3 (S3), Station 4 (S4) and Station 5 (S5) (Map 2) were selected for the present study. Table 2 provides a description of each station's location.

3.3 Study period

The research was conducted for a period of 12 months from December, 2020 to November, 2021 corresponding to four seasons: winter (December, 2020 to February, 2021), summer or pre-monsoon (March, 2021 to May, 2021), monsoon (June, 2020 to August, 2021), post-monsoon (September, 2021 to November, 2021).



Map 1. Location map of Murshidabad district, West Bengal, India



Map 2. Satellite view of the Bansabati beel showing sampling sties (Source: Google Earth)

Plate 3.1. Views of Bansabati beel of different seasons

Table 3.1 Morphometric characteristics of the Bansabati beel

Sl. No.	Parameter	Particulars
1.	Total area	500 ha (approximately)
2.	Length of the beel	4.25 km
3.	Type of beel	Open; Riverine floodplain
4.	Depth of the beel	0.5 m- 4.4 m
5.	Inflowing rivers	Bansloi and Pagla

Table 3.2 Sampling stations in the Bansabati beel

Station code	GPS location	Description of the site
Station 1 (S1)	24°29'18"N 88°00' 24"E	Near Nazirpur (connection with Pagla river and the Bansabati beel)
Station 2 (S2)	24°28'43"N 88°00' 38"E	Near Aluani (near agricultural land)
Station 3 (S3)	24°28'10"N 88°00' 46"E	South of Aluani (middle of the beel)
Station 4 (S4)	24°27'39"N 88°00' 29"E	Near Takshak (less human interference)
Station 5 (S5)	24°27'29"N 87°59' 42"E	Near Hasampur (Terminal part of the beel)

3.4 Collection of samples

Water and sediment samples were collected once a month on the site of the Bansabati beel in five different stations viz., S1, S2, S3, S4 and S5 in the morning hours between 6.30 A.M. and 9.00 A.M. on each sampling day and fish samples were collected for assessing the diversity in the Bansabati beel during harvesting hours between 5 A.M and 7 A.M.

3.4.1 Water sample

Water samples were collected in a clean and dry 300 ml BOD bottle avoiding any air bubble entering into it for estimation of dissolved oxygen, free carbon dioxide, total alkalinity and total hardness. For estimation of other chemical parameters such as nitrate-nitrogen, phosphate-phosphorus and chlorophyll, water samples were separately collected by using clean and dry labelled plastic bottles and were analysed in the Scientific Research Laboratory, NABL Accredited Laboratory, Jadavpur, Kolkata and Department of Fisheries Resource Management, Faculty of Fishery Sciences, WBUAFS, Kolkata. The water parameters like temperature, transparency, pH, total dissolved solids, dissolved oxygen, total alkalinity, free carbon dioxide, and total hardness were analyzed at the site itself.

3.4.2 Collection of sediment samples

Sediment samples were collected for the estimation of pH and organic carbon on monthly basis using clean and dry labelled plastic bags. Samples were analyzed in the Scientific Research Laboratory, NABL Accredited Laboratory, Jadavpur, Kolkata and Department of Fisheries Resource Management, Faculty of Fishery Sciences, WBUAFS, Kolkata.

3.4.3 Collection and identification of fish sample

Fish samples were collected on sampling day or other than sampling day with help of local fishers to ascertain ichthyofaunal diversity. Fishes were normally caught by gears such as cast net, gill net, drag net, push net, box trap and hook & line. Fish specimens collected were identified on the field itself and individually each species was enumerated to ascertain the species composition, abundance and diversity. Fish species that could not be identified were cleaned thoroughly, preserved in 10% formalin and brought to the laboratory for further identification (Talwar and Jhingran, 1991; Froese and Pauly, 2020). The binomial nomenclature and systematic position were followed as per the Catalogue of Fishes of California Academy of Sciences (Fricke *et al.,* 2022). The fish were categorised into four groups (modified after Odyuo and Nagesh, 2012; Pandit *et al.,* 2021) based on their frequency of occurrence *viz*., most abundant (++++; recorded in 12 sampling months), common (+++; recorded in 10-11 sampling months), moderate (++; recorded in 8-9 sampling months); rare (+; recorded in 6-7 sampling months). Fishery importance of the fish species, feeding habits, trophic level and IUCN Red List status was noted down from available literature (Chutia *et al.*, 2018; Sandhya *et al.,* 2019; Froese and Pauly, 2022; IUCN, 2022).

The collected fish samples were washed with clean water to remove the sediments and other materials from the fish body. Fishes were then kept on laminated graph paper and / or clean surface and pictures were captured using Nikon Coolpix B700 camera (20.2 megapixel).

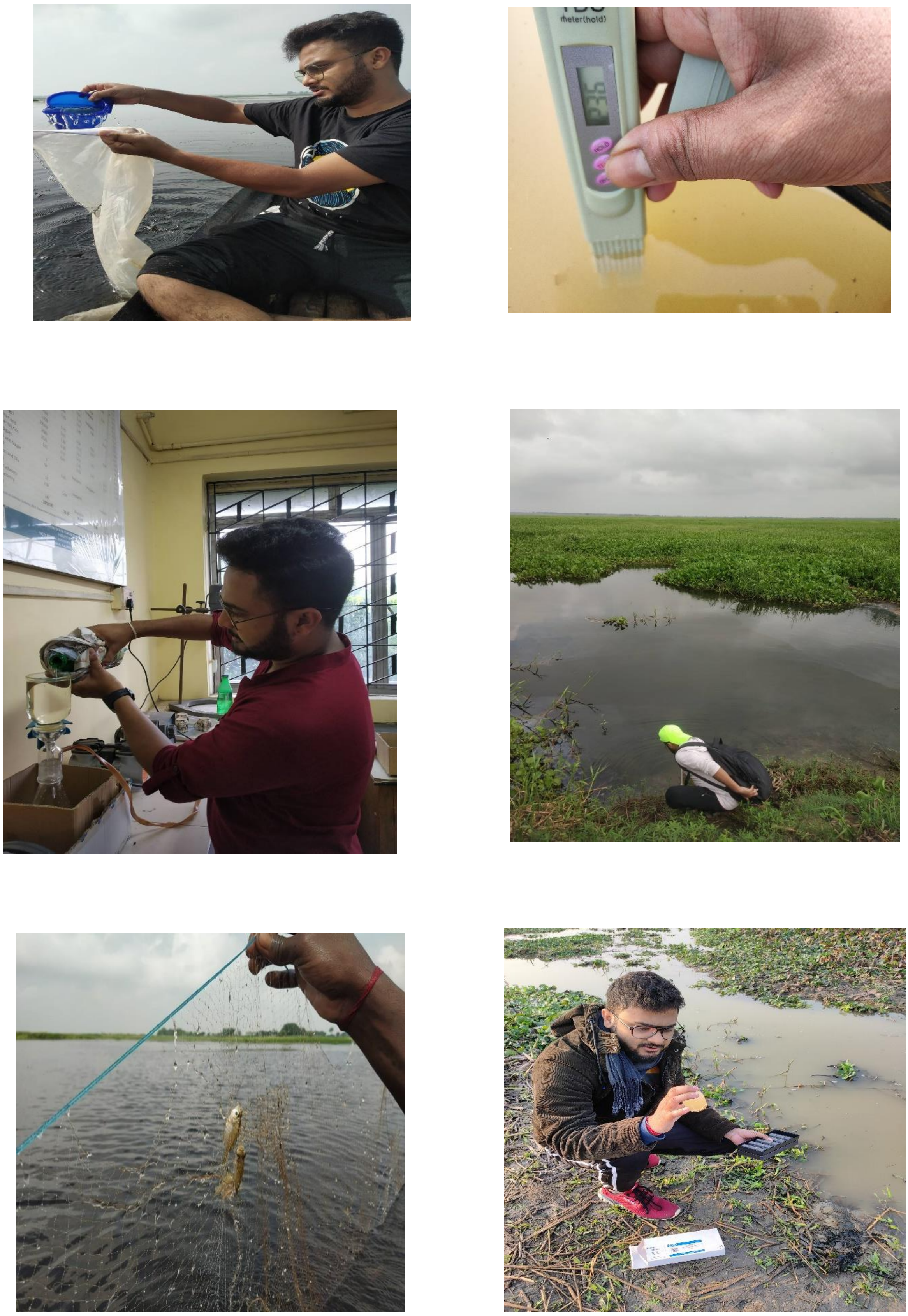


Plate 3.2 Data collection and analysis of parameters

3.4.4 Phytoplankton

For the phytoplankton analysis, 50 l of water was filtered through a plankton net made up of bolting silk using a 10 l capacity plastic container. Immediately after filtering out the water, the plankton biomasses were transferred to polyethylene specimen bottles (100 ml) filled with 5% of formalin for further analysis.

3.5 Analysis of physico-chemical parameters of water

Physico-chemical parameters of water were estimated in triplicate by following standard methods (APHA, 2017) as described below.

3.5.1 Temperature

Air temperature and water temperature were recorded by centigrade thermometer (Range: 0°C – 50°C) on site and expressed as degree Celsius.

3.5.2 Transparency

Transparency was determined using Secchi disc (20 cm diameter) and expressed in centimeter (cm).

3.5.3 pH

pH of the water sample was measured directly on the site by using the digital pH meter containing a sensor (Hanna, Portugal).

3.5.4 Total dissolved solids (TDS)

The TDS was measured by TDS meter (HiMedia) and expressed as mg/l.

3.5.5 Dissolved oxygen (DO)

Procedure

Dissolved oxygen (DO) was estimated by Winkler's iodometric method. The water samples were collected on the sampling day and immediately fixed with 1 ml of Winkler's A (manganous sulphate) and 1 ml of Winkler's B (alkaline-iodide-azide) solutions. When precipitate has settled sufficiently to a level clear supernatant above the manganese hydroxide floc, 1 ml of concentrated sulphuric acid was added. After the colour turned to golden, the sample was titrated against 0.025 N sodium thiosulphate solution using starch as an indicator till the sample became colourless. The DO content in the water sample was determined by the following equation and expressed as mg/l.

$$\text{Dissolved oxygen (DO) as mg/l} = \frac{\text{ml of sodium thiosulphate used for titration x 1000 x 8}}{\text{ml of sample taken for anlaysis x 40}}$$

3.5.6. Free carbon dioxide

Procedure

Fifty ml of water sample in a conical flask was taken and 5-10 drops of phenolphthalein indicator was added to it. If there was no free carbon dioxide the colour turned pink. If the sample remained colourless, N/44 sodium hydroxide solution was added drop by drop from a graduated pipette to restore the pink colour. Recorded ml of N/44 sodium hydroxide used during this titration. Free carbon dioxide (mg/l) was calculated as

$$\text{Free carbon dioxide } (CO_2) \text{ as mg/l)} = \frac{\text{ml of N/44 sodium hydroxide used for titration} \times 1000}{\text{ml sample taken for analysis}}$$

3.5.7 Total alkalinity

Procedure

Total alkalinity of water sample collected from the beel was estimated by acid-base titration. The 50 ml of water sample was taken in a 100 ml conical flask. Then 2-3 drops methyl orange indicator was added to it. It was then titrated against 0.02 (N) sulphuric acid. The end point was indicated by the change of colour from orange to pink and expressed as mg/ l as calcium carbonate ($CaCO_3$) after calculation with the help of folloiwng formula

$$\text{Alkalinity as mg } CaCO_3\text{/l} = \frac{\text{A x N x 50000}}{\text{ml of sample taken for analysis}}$$

Where, A = ml of standard H_2SO_4 consumed; N = Normality of standard acid

3.5.8 Total hardness

Procedure

Total hardness of the collected water samples was estimated by Ethylenediaminetetraacetic acid (EDTA) titrimetric method. Fifty ml of water sample was taken in a 100 ml conical flask. Then 1 ml of ammonium buffer was added in to the samples to increase the pH to about 10.0-10.1 and 2-3 drops of Eriochrome Black-T was added as indicator. Resultant was titrated against standard EDTA titrant with continuous stirring, until the last reddish tinge disappears. The last few drops were added at 3-5 second intervals. The end point was indicated by changing of reddish colour to blue. Hardness as mg/l was calculated as

$$\text{Hardness as mg mg/l} = \frac{A \times 1 \times 1000}{\text{ml of sample taken for analysis}}$$

Where, A = ml of EDTA titrant (1.0 ml EDTA equivalent to 1.0 mg $CaCO_3$)

3.5.9. Nitrate-nitrogen

Procedure

To 25 ml water sample, 1 ml of alkaline buffer and 0.5 ml of reducing agent were added and kept in the dark for 20 h for complete reduction. Added 1 ml of acetone to the solution. After 8 minutes, 0.5 ml sulphanilamide solution and 0.5 ml NED (N-(1-naphthyl) ethylenediamine) solutions were added for development of pink azo-dye. The absorbance was measured at at 543 nm in UV spectrophotometer. The nitrate-nitrogen concentration of the water sample was computed from the standard curve and the result was expressed as mg/l.

3.5.10 Phosphate-phosphorus

Procedure

Phosphate-phosphorus was estimated spectrophotometrically following stannous chloride method. 10 ml of filtered water sample was taken in a 25 ml test tube and 2 drops of phenolphthalein indicator was added, if the solution turned pink, strong acid solution (H_2SO_4 + HNO_3) was added drop wise until the pink colour disappeared. Then 0.4 ml of ammonium molybdate ($(NH_4) MO_7O_{27}$) reagent and 0.05 ml of stannous chloride ($SnCl_2$) indicator were added and mixed thoroughly till blue colour developed. The absorbance of the solution was taken after 10 minutes and before 12 minutes of addition of stannous chloride through spectrophotometer at 690 nm wavelength. The phosphate-phosphorus concentration of the water sample was computed from the standard curve and the result was expressed as mg/l.

3.6 Analysis of sediment parameters

The sediment samples were air dried and pulverized to fine size and sieved through a standard test sieve (IS No. 40s, pore size 0.425 mm). Well dried and sieved soil samples were stored in polythene bags for estimation of pH, organic carbon, total nitrogen and C/N ratio.

3.6.1 pH

For the estimation of soil pH electrometrically, 10 g of soil sample was added to 50 ml of distilled water (1:5) in a beaker and vigorously shacked for 5 minutes. Then the mixture was kept for 30 minutes. The electrodes of pH meter (Make: Systronics, Model: MK-VI) were immersed into the solution and the pH value was recorded after proper calibration.

3.6.2. Soil organic carbon (%)

For the estimation of organic carbon, 1 g air dried powered sediment soil sample was digested with 10 ml (N) potassium dichromate ($K_2Cr_2O_7$) and 20 ml concentrated H_2SO_4. After digestion, the digested sample was kept for 30 minutes at dark. The sample was then diluted with 200 ml distilled water and 10 ml orthophosphoric acid. 1 ml diphenyl amine indicator was added to it. It was then titrated against 0.5N ferrous ammonium sulphate ($Fe_2 (NH_4)_2SO_4$) (Mohr′s salt) until brilliant green colour appeared (Wakeel and Riley, 1957). It was expressed as the percentage of organic carbon and was calculated by following formula:

Organic carbon (%) = $[10\times (B-S) \times 0.03\times 100] / (B\times W)$

Where, B = Volume of $Fe_2 (NH_4)_2SO_4$ consumed by the blank (ml); S= Volume of $Fe_2 (NH_4)_2SO_4$ consumed by the sample (ml); W= Weight of the sample (g)

3.6.3 Total nitrogen

Procedure

10 g of soil sample was taken in a Kjeldahl flask. 20 ml of conc. H_2SO_4 and 0.5 g salicylic acid were added and kept for 0.5 h. Then added 2 g of sodium thiosulphate, 1 g of copper sulphate and 5 g of potassium sulphate and digested the mixture until a white to bluish colour liquid was formed. Water was allowed to cool and dilution. Made it alkaline with 80 ml of 12N NaOH, added a few beads of glass and distil. Collected the distillate in a conical flask containing 20 ml of 0.1N H_2SO_4 and a few drops of methyl red indicator was added. About 120-150 ml of distillate was collected. Excess of 0.1N H_2SO_4 was titrated with 0.1N NaOH till the solution turns colourless. Total nitrogen was calculated and experessed in percentage as follows

Total nitrogen (%) = (20- ml of NaOH required for titration) x 0.014

3.7 Analysis of plankton

3.7.1 Qualitative analysis of phytoplankton

Diversity of phytoplankton was studied by taking replicates of sample on slides. Identification was done under different magnifications by using of an inverted microscope (Olympus CH20), at a magnification of 100x–400x. Phytoplankton was identified up to genus level using different standard keys (Needham and Needham, 1963; Prescott, 1954; Edmondson, 1959; Belcher and Swale 1976; Adoni, 1985; APHA, 2005; Bellinger and Sigee, 2010).

3.7.2 Quantitative analysis of phytoplankton

One millilitre of subsample (1 ml) was taken with a wide mouthed pipette and poured into the counting cell of the Sedgwick Rafter. After allowing for settle some time they were counted. At least 5 such counting was made for each group. The value which represents abundance was calculated as cells per litre (Dhanasekaran *et al.*, 2017).

3.7.3 Calculation of plankton

Total number of plankton present in 1 litre of water sample was calculated using the following formula (Santhanam *et al.*, 1989)

$$N = \frac{n \times v}{V}$$

Where, N = Total number of plankton per liter of water filtered; n = Average number of plankton in 1 ml of plankton sample; v = Volume of plankton concentrated (ml); V = Volume of total water filtered (liter);

The population of plankton was expressed in average, number of individuals per litre (No. /l)

3.8 Analysis of macrophytes

Macrophytes from the Bansabati beel were collected from five sites. Subsequently, the macrophytes were identified as per APHA (2005) and Holmes (1992).

3.9 Species diversity indices

3.9.1 Species richness index (d) or Margalef's index

The species richness index (d) or Margalef's index (Margalef, 1958) was used to evaluate the community structure using the following formula.

$$\boldsymbol{d} = (\boldsymbol{S} - \mathbf{1})/\mathbf{ln}\boldsymbol{N}$$

Where 'S' is the number of species in a population and 'N' is the total number of individuals in 'S' species.

3.9.2 Simpson diversity index (1- λ')

Simpson diversity index (Simpson, 1949), one of the most used indices to measure biodiversity, was calculated as

$$\mathbf{1} - \boldsymbol{\lambda}' = \mathbf{1} - \sum \boldsymbol{n}(\boldsymbol{n} - \mathbf{1}) / \boldsymbol{N}(\boldsymbol{N} - \mathbf{1})$$

Where, 'n' is the total number of individuals of a particular species and 'N' is the total number of individuals of all species.

3.9.3 Shannon-Wiener diversity index (H')

Shannon-Wiener diversity index (H') (Shannon and Wiener, 1949) was calculated as

$$\mathbf{H}' = -\sum_{i=1}^{s} (\mathbf{pilnpi})$$

Where 'S' is the total number of species, denotes counts denoting the i^{th} species ranging from 1 to S; 'pi' is the proportion that the i^{th} species represents in terms of individuals with respect to the total number of individuals in space.

3.9.4 Pielou'sevenness Index (J')

Pielou's evenness Index (J') (Pielou, 1966) measures diversity along with species richness and was calculated using the formula,

$$J' = H / \ln S$$

Where 'H' denotes the Shannon-Wiener diversity index and 'S' indicates the total number of species in the sample.

Diversity indices were presented season-wise viz., pre-monsoon, monsoon, post-monsoon and winter.

3.10 Analysis of trophic status

For evaluating trophic status of the Bansabati beel total Secchi disc reading, total phosphorus and chlorophyll *a* were estimated.

3.10.1 Determination of total phosphorus (TP)

The water sample was digested by per sulphate methods as given in APHA (2005). The digestion was carried out by adding sulphuric acid (H_2SO_4) solution and potassium per sulfate ($K_2S_2O_8$) to water sample and boiling gently on preheated hot plate. The digested water sample was diluted to a known volume with distilled water and the phosphate content was measure by ascorbic acid method as given in APHA (2005).

3.10.2 Determination of chlorophyll *a* (CA)

Chlorophyll *a* in the water sample was measured by the method of spectrophotometric determination of Chlorophyll as given by APHA (2005). Chlorophyll *a* in measured volume of water sample was concentrated by filtration through a glass fiber filter. The photo-pigments were extracted from the phytoplankton by grinding the filter and steeping the filter slurry in 90% aqueous acetone solution overnight. The filter slurry was centrifuged to clarify the solution and then supernatant was transferred to a glass spectrophotometric cell. The sample's absorbance was measured at 750 and 664 nm before acidification and 750 and 665 nm after acidification with 0.1N HCL. Concentrations of Chlorophyll –a was reported in ug/l. Calculation was done as given bellow

Chlorophyll *a* (ug/l) = $\frac{26.7(corr.664 - corr.665) volume\ of\ extract\ in\ l}{\frac{volume\ of\ sample\ in\ l}{1000} \times 1\ cm}$

corr.664=Absorbance at 664 before acidification-Absorbance at 750 before acidification
corr.665=Absorbance at 665 after acidification-Absorbance at 750 after acidification

3.10.3 Carlson's Trophic State Index (TSI) calculation

Carlson Trophic State Index (CTSI) was calculated using the following formula (Carlson, 1977).

A. Trophic State Index (TSI) for Chlorophyll *a* (TSI Chl-a) = 9.81In Chlorophyll-a (µg/l) + 30.6

B. Trophic State Index (TSI) for Secchi disk depth (TSI SDD) = 60-14.41 ln Secchi depth (meters)

C. Trophic State Index (TSI) for total phosphorus (TSI TP) = 14.42 ln total phosphorous (mg/l) + 4.15.

Carlson's Trophic State Index (CTSI) = [TSI (TP) +TSI (CA) +TSI (SD)] / 3

Table 3.3 Carlson's Classification based on Trophic State Index (TSI) (Modified by Melcher, 2013)

Classification	Sub-classification	Trophic state index
Oligotrophic	Strongly oligotrophic	0-25
	Oligotrophic	26-32
	Slightly oligotrophic	33-37
Mesotrophic	Slightly mesotrophic	38-42
	Mesotrophic	43-48
	Strongly mesotrophic	49-53
Eutrophic	Slightly eutrophic	54-57
	Eutrophic	58-61
	Strongly eutrophic	62-64
Hyper-eutrophic	Hyper-eutrophic	65+

3.11 Index of biotic integrity (IBI)

Three sites were chosen for the IBI investigation, namely S1-near Nazirpur (connection between the Pagla River and the Bansabati beel; 24°29' 18"N 88°00' 24"E); S3-south of Aluani (middle of the beel); and S5-near Hasampur (terminal section of the beel; 24°27' 29"N 87°59' 42"E). The middle section of the *beel*, which is south of Aluani (S3- 24°28' 10"N 88°00' 46"E), was chosen as the reference site because it had fewer point sources of pollution, less human interference, and was least disturbed. In contrast, S1 and S5 are exposed to a variety of anthropogenic stressors such as agricultural runoff, filling up the shallow portion of the lake, and creating agriculture plots. The *beel* was sampled every month from October 2021 to December 2021. Fish samples were taken at three sampling sites in the morning hours as stated earlier using gears such as cast nets and gill nets. This period is advantageous since most fishing spots are active. Secondly, during post-mating season of the majority of resident fishes has concluded, representative samples of the fish community are collected from each location. Fish with confirmed identities were returned to the *beel*, while those that could not be identified were stored in 10% formalin and taken to the laboratory for further identification. Fish species were identified as per Talwar and Jhingran (1991), while the California Academy of Sciences' Catalogue of Fishes (Fricke *et al.*, 2022) was followed for assigning binomial nomenclature and systematic position.

3.11.1 IBI modification for Bansabati *beel*

Altering the IBI for a fresh ecosystem requires basic ecological knowledge that includes information about native and non-native fish species, trophic guilds, habitat guilds, and the tolerance range of those species in various environments. The current study consulted published literature on fish biology and taxonomy (Talwar and Jhingran, 1991; Jayaram, 1999; Froese and Pauly, 2020). The present study categorised metrics into four groups after Karr *et al.* (1986), which were named "taxonomic richness", "trophic guilds", "habitat composition", and "fish health and abundance". Modifications to traditional metrics were made to suit the local environmental conditions. The metric for the "number of native species" (Lyons, 1992) was a modification of the "total number of species" by Karr (1981), and the "number of native families" (Lyons, 1992) was an addition. These characteristics were established using regional ichthyological references (Bleekar, 1853; Chaudhuri, 1912; Day, 1876; Sarkar *et al.*, 2020) and general standing of the fishes' environments. Witkowski (1992) and Oberdorff and Hughes (1992) observed that in areas of long and extensive human habitation, entire families were either destroyed or endangered. This metric will help to understand the stage of degradation of the aquatic body. Environmental degradation is indicated by the decrease in the number of native species and the increased presence of non-native species. Thereafter, the distinction between native and non-native species is an important metric (Karr *et al.,* 1986). Sucker species were replaced by native minnows, taking into consideration their local availability and strong response to changes in water quality and habitat of wetlands. Similar changes in metrics were made in previous studies (Hughes and Gammon, 1987; Simon, 1998).

Some fish assemblages exhibit robust population declines in response to habitat loss. Therefore, IBI developed the "number of intolerant species" as one of the metrics to estimate the habitat status of the water body under study (Karr, 1981). With increasing anthropogenic pressure, these intolerant species tend to withdraw. However, their population increases once a favourable environmental condition resurfaces. This intolerant category was incorporated into the current study based on fish base resilience data (Froese and Pauly, 2020) and recent abundance data collected during the present study. ‘Number of darter species’, ‘number of sucker species’, 'percentage of green sunfish species’, and ‘number of sunfish species’ (Karr, 1981) were substituted by ‘number of benthic species’ and ‘number of water column species’ (Ganasan and Hughes, 1998), taking into consideration their local availability, along with their sensitive response towards siltation, pH, and low dissolved oxygen (Minns *et al.*, 1994). Karr *et al.* (1986) and Hughes *et al.* (1998) opined that a rise in the number of species of benthic and water column species is a sign of good habitat and water quality.

The variety of a fish assemblage's eating patterns indicates the trophic composition. The underlying cause of the changes in trophic pattern provides more support for IBI. The trophic structure is determined by the proportion contributing to insectivore, piscivore, and omnivore populations (Karr *et al.,* 1986). The metrics "percentage of individuals as omnivores" and "percentage of individuals as carnivores" were obtained from the original study (Karr, 1981), and “percentage of individuals as herbivores” (Ganasan and Hughes, 1998) was an addition in consideration of the local circumstances of the wetland under study. Carnivores primarily consume fish, smaller vertebrates, and large invertebrates, and their numbers show a decreasing tendency under habitat disturbances. The herbivores principally feed on plants, so their numbers can sense habitat alterations.

Two metrics were retrieved from the original study, viz., “the total numbers of individuals in and in the sample” and “the percentage of individuals with disease or anomalies” (Karr *et al.,* 1986). A decreased value of the total number of individuals may indicate a stressed environment and poor nutrient availability. On the other hand, degraded habitat quality is represented by an increase in percentage anomalies (Hughes *et al.,* 1998). It was also decided to retain the "percentage of individuals as non-native" metric that was introduced by Ganasan and Hughes (1998). The presence of non-native species indicates anthropogenic water disruptions, with reduced native species survival.

Karr *et al.* (1986) proposed the IBI scoring method, which was then used by Hughes and Gammon (1987) and Ganasan and Hughes (1998). For this research, IBI scoring criteria (5-3-1) were devised in accordance with Hughes *et al.* (1993) to determine the wetland's health status. The number of native species, number of native families, number of native minnows, benthic species, water column species, intolerant species, and proportion of herbivores and top carnivores were the metrics that were indicative of undisturbed circumstances. When deterioration rises, this metric will decline. However, metrics that were deemed suggestive of disturbed circumstances were the percentage of omnivores, the percentage of non-native individuals, and the percentage of individuals with disease or anomalies that rise with environmental degradation owing to the adaptations of the affected individuals (Ganasan and Hughes, 1998).

The IBI scores were then taken for qualitative assessment. The best and worst situations for each metric were chosen and attributed a score in between 5 (best) and 1 (worst), respectively (Table 3.3). The IBI is the sum of the 12 metrics in the 10 quality classes during the study period. Hughes *et al.* (1998), Karr *et al.* (1986), and Ganasan and Hughes (1998) were consulted for the qualitative assessment (acceptable, slightly impaired, and impaired) of IBI scores. An **'impaired'** IBI score was ‘**less than 60 percent of the highest score’ (**Karr *et al.* 1986 called this as ‘poor’ or ‘very poor’). IBI scores that fell ‘**below 60% of the maximum’** observed were considered as **‘unacceptable’ or ‘impaired’**. A **'marginally impaired'** score was **‘between 60 and 80 percent of the highest score**’. Karr *et al.* (1986) assessed these scores to be ‘fair’. IBI scores that exceeded 80% of the highest observed value were categorically ‘acceptable’.

3.12 Statistical analyses

Diversity indices were presented season-wise viz., pre-monsoon, monsoon, post-monsoon and winter by Paleontological statistics software Package for Education and Data analysis (PAST) version 4.09. One-way ANOVA was performed using Statistical Package for Social Sciences (SPSS) version 22.0 to determine whether there were significant differences across seasons. Two-way ANOVA was performed to compare the significant differences between water and sediment quality parameters across months and sites using SPSS version 22.0. Post hoc analysis was performed using Duncan's multiple range test, wherever applicable. Pearson correlation coefficient (r) was determined to know the extent of relationship among water and sediment quality parameters. Relationship between fish assemblages and environmental variables were investigated using canonical correspondence analysis (CCA) using PAST v.4 software.

Table 3.4 Modified IBI metrics and scoring criteria adapted for the present study (Modified from Fausch *et al.*, 1984; Karr *et al.*, 1986; Hughes and Gammon, 1987; Hughes *et al.*, 1993; Ganasan and Hughes, 1998)

Category	**Metric**	**Scoring criteria**		
		5	**3**	**1**
Species richness and composition	Number of native species	>28	14-28	<14
	Number of native families	>11	7-11	<7
	Number of native minnows	>7	4-7	<4
Habitat composition	Number of water column species	>15	7-15	<7
	Number of bottom dweller species	>10	7-10	<7
	Number of intolerant species	>8	4-8	<4
Trophic composition	Percentage individuals as omnivores	<35	35-70	>70
	percentage individuals as herbivores	>20	10-20	<10
	percentage individuals as top carnivores	>36	18-36	<18
Fish health and abundance	Total number of individuals	>1000	500-1000	<500
	percentage individuals as non-native	<1	1-10	>10
	percentage individuals with anomalies or disease	<2	2-8	>8

Chapter 2

RESULTS AND DISCUSSION

4. RESULTS AND DISCUSSION

4.1 Physico-chemical parameters of water at the Bansabati *beel*

The productivity and state of the water bodies are significantly impacted by physico-chemical parameters. Physical and chemical circumstances, key indicators of water quality, fluctuate throughout the course of the year, and any modification to these factors may have an impact on the growth, maturation, and survival. Physiology and biology of living things such as the present investigation included the study of water quality parameters of five stations in the Bansabati *beel* namely, S1 (24°29' 18''N 88°00' 24''E) near Nazirpur (connection between the Pagla River and the Bansabati *beel*); S2 (24°28' 43''N 88°00' 38''E) near Aluani; S3 (24°28' 10''N 88°00' 46''E) south of Aluani (middle of the *beel*); S4 (24°27' 39''N 88°00' 29''E) near Takshak; and S5 (24°27' 29''N 87°59' 42''E) near Hasampur (terminal of the *beel*), during the period between December, 2020 and November, 2021. The results obtained from the study are presented and discussed below.

4.1.1 Water temperature

Temperature is one of the important parameters which greatly influence not only the pond dynamics (Wootten, 1996) but also regulate various physiological activities of fishes, thereby, affecting productivity of an ecosystem. It is influenced by topography, solar radiation, weather, and water depth. It also influences distribution of flora and fauna in aquatic ecosystem. The rate of plant respiration and the metabolic activity of the microbiota both increase with temperature, increasing the need for oxygen (Bhatnagar and Devi, 2013). Consequently, the organism in water is directly impacted by the temperature (Mukherjee, 2011). According to Ayyappan *et al*. (2006), many warm-water fish prefer temperatures range between 24°C and 30°C under ideal circumstances.

The air and water temperature were recorded at monthly intervals and the results are presented in Table 4.1 and 4.2 and as well as in Figure 4.1 and 4.2. The air temperature varied between 19.60°C at S3 in the month of January and 34.70°C at S5 in the month of May; and water temperature fluctuated between 16.60±0.00°C at S3 in the month of January and 32.80±0.00°C at S5 in the month of May during the study period.

In the five stations (S1, S2, S3, S4, and S5) of the *beel*, the maximum water temperature was observed (32.63±0.05°C, 31.53±0.05°C, 32.40±0.00°C, 31.33±0.05°C, 32.80±0.00°C) in the month of May. A decreasing trend of water temperature was observed from July onwards and the lowest water temperature recorded in the month of January (S1: 17.80±0.00°C, S2: 16.93±0.05°C, S3: 16.60±0.00°C, S4: 16.96±0.05°C, S5:

17.83±0.05°C). Though the lowest temperature was recorded in January, the lower temperature was persisted in February thereafter it showed an increasing trend.

Two-way ANOVA indicated (Table 4.3) a significant difference ($P<0.05$) of water temperature among the months and as well as among the stations. Water temperature was significantly higher ($P<0.05$) in May as compared to other months of the year. Water temperature of S4 was significantly lower ($P<0.05$) than that of other sites (S1, S2, S3, S5) during the study period. Water temperature has a negative correlation (Table 4.22) with dissolved oxygen (r= -0.7867), alkalinity (r= -0.8386), hardness (r= -0.9179), transparency (r= -0.485) and water pH (r= -0.6365). Water temperature displayed (Appendix II) a significant positive correlation ($P<0.05$) with TDS (r= 0.2954), phosphate-P (r= 0.6828), nitrate-nitrogen (r= 7721) and free carbon dioxide (r= 0.6660).

Due to intense solar radiation, a warm atmosphere, and a drop in water level, the water temperature was high in the summer. Then, starting from July, the water temperature began to decline owing to a decrease in solar intensity as well as the influence of rainwater and surface runoff, which raised the lake's water level. It was revealed that the winter months had the lowest temperature of water, which was presumably caused by the colder air and the shorter solar day. The current result is consistent with prior studies at Silsakho wetland in Kamrup district, Assam (Baruah and Sharma, 2013); Loktak Lake in Manipur, Northeast India (Laishram and Dey, 2014); Baskandi anua Lake, Cachar District, Assam, North East India (Devi *et al*., 2016). In an open wetland, Puthiyottil *et al*. (2021) recorded mean temperature was 27.35±6.86°C at Katiganga wetland of Murshidabad district. Santragachi Jheel in West Bengal, India, had an average temperature of 27.58 ±3.29°C (Patra *et al*., 2010). Sarkar *et al*. (2020) reported the water temperature ranges from 17°C to 31.4°C in Chaltia wetland, a gangetic floodplain wetland, situated in Murshidabad district, West Bengal. Panigrahi *et al*. (2014) reported, from their investigation, mean temperature ranging from 27.03ºC to 32.03ºC at Kalyani Lake, West Bengal. According to Sarkar *et al*. (2020) three floodplain wetlands, Bhomra, Mathura and Chandania had an average water temperature of 28.42±2.55ºC, 28.90±3.33ºC and 29.93±3.60ºC respectively. Singh *et al*. (2017) observed that the temperature was in between 20.6 °C and 31.0 °C in Bhara-haripota *beel* in Bhamanghata, South 24 Parganas district of West Bengal. Ghosh and Biswas (2018) reported that the mean temperature was 27.64±6.56 ºC at Chhariganga oxbow lake in Nadia district, West Bengal. The findings of the present study is well within the range required for the growth of fishes (ranges between 24°C and 30°C, Ayyappan *et al*., 2006) in the *beel* and in agreement with the findings of the above researchers (Sarkar *et al*., 2020; Panigrahi *et al*., 2014).

Table 4.1 Monthly variation in air temperature (^{0}C) at the Bansabati *beel*

Stations	December, 2020	January, 2021	February, 2021	March, 2021	April, 2021	May, 2021	June, 2021	July, 2021	August, 2021	September, 2021	October, 2021	November, 2021	Average
S1	20.7	19.9	25	30.7	32.7	34.6	33.5	32.2	31.7	30.9	29.6	28.6	29.17
S2	20.4	19.7	24.7	30.6	32.6	34.3	33.6	31.8	31.5	30.7	29.3	28.3	28.95
S3	20.5	**19.6**	24.3	30.5	32.4	34.5	33.3	32.1	31.4	30.8	29.2	28.2	28.90
S4	20.6	19.7	24.4	30.4	32.3	34.6	33.4	31.9	31.3	30.6	29.5	28.3	28.91
S5	20.8	19.9	24.6	30.8	32.5	**34.7**	33.5	32.1	31.6	30.6	29.6	28.5	29.10

Table 4.2 Monthly variation in water temperature (^{0}C) of Bansabati *beel*

Stations	December, 2020	January, 2021	February, 2021	March, 2021	April, 2021	May, 2021	June, 2021	July, 2021	August, 2021	September, 2021	October, 2021	November, 2021	Average
S1	18.90±0.10	17.80±0.00	23.33±0.05	28.90±0.00	30.60±0.00	32.63±0.05	31.60±0.00	30.10±0.00	29.60±0.00	29.83±0.05	27.50±0.00	26.50±0.00	27.27
S2	17.80±0.00	16.93±0.05	22.90±0.00	28.70±0.00	30.53±0.05	31.53±0.05	30.53±0.05	29.70±0.00	28.50±0.00	28.50±0.00	27.43±0.05	25.40±0.00	26.53
S3	17.40±0.00	**16.60±0.00**	22.70±0.05	27.50±0.00	29.40±0.00	32.40±0.00	31.30±0.05	30.00±0.00	28.70±0.05	28.60±0.00	26.30±0.00	25.20±0.05	26.34
S4	18.93±0.05	16.96±0.05	22.83±0.05	27.80±0.00	30.30±0.00	31.33±0.05	30.43±0.05	29.80±0.00	28.90±0.00	29.40±0.00	26.70±0.05	25.80±0.00	26.59
S5	18.70±0.00	17.83±0.05	23.86±0.05	28.70±0.00	29.63±0.05	**32.80±0.00**	31.70±0.00	30.13±0.05	29.53±0.05	28.73±0.05	27.70±0.00	26.63±0.05	27.16

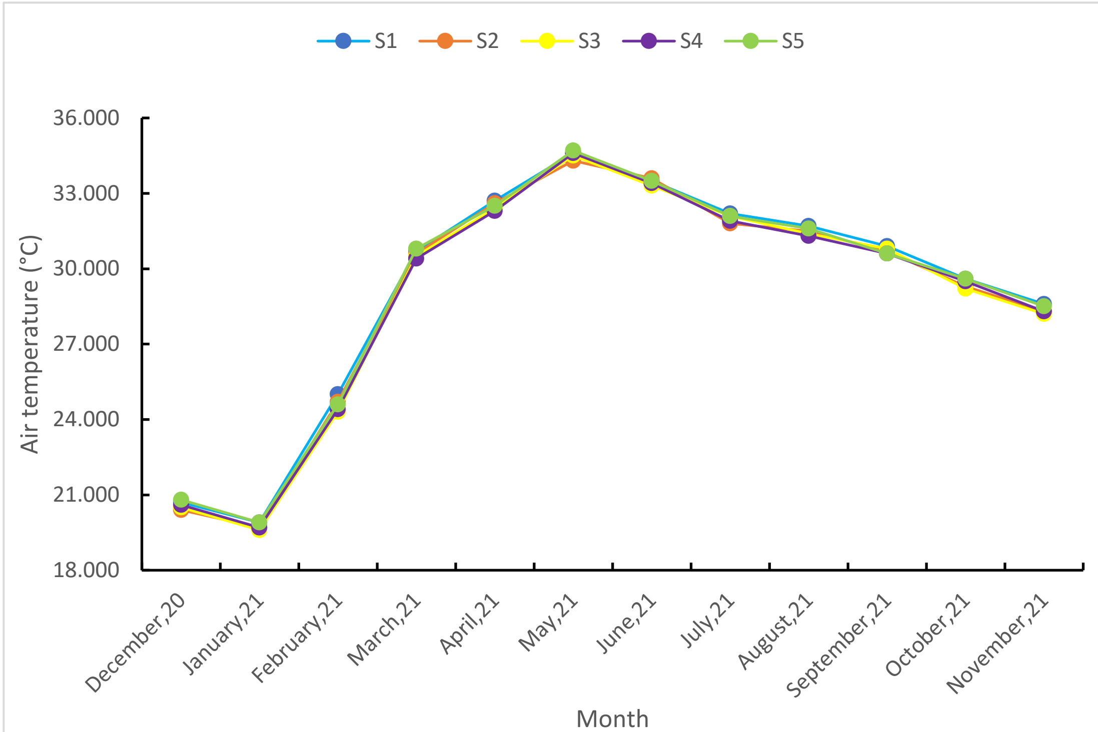


Figure 4.1 Monthly variation in air temperature (^{0}C) at the Bansabati *beel*

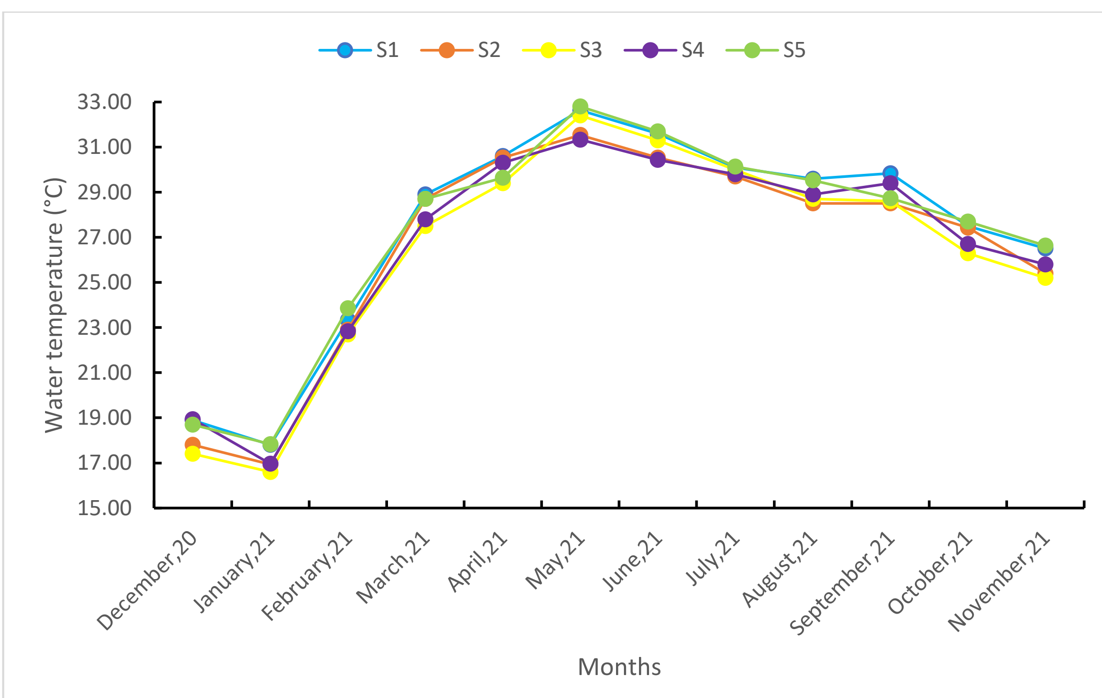


Figure 4.2 Monthly variation in water temperature (^{0}C) of Bansabati *beel*

Table 4.3 Two way ANOVA (with replication) to analyse month wise and station wise variation of water temperature of Bansabati *beel*

Source	Sum of Squares	DF	Mean Square	F	P
Months	3877.705	11	352.519	1831.102	<0.001
Stations	22.817	4	5.704	29.630	<0.001
Months*Stations	22.899	44	0.520	2.703	<0.001
Residual	23.102	120	0.193		

4.1.2 Transparency

The easiest approach to assess the underwater light environment in aquatic habitats is by measuring water transparency. Plankton density, suspended soils, and solids like clay and silt particles are all factors that affect the water transparency. Since 1865, limnologists have utilised transparency, as determined by the Secchi disc depth (SDD), as a common and affordable way to evaluate the quality of water (Kalff, 2002). Boyd and Lichtkoppler (1979) hypothesised that water transparency between 30 cm and 60 cm, is often sufficient for optimal fish productivity and 30 cm or less may inhibit the establishment of plankton blooms.

The results of water transparency at monthly intervals in the five sampling sites during the study period are presented in Table 4.4 and Figure 4.3. The highest mean water transparency was recorded during the month of January at S1, S2, S3, S4 and S5 were 113.97±1.05 cm, 119.70 ±0.85 cm, 121.50 ±0.62 cm, 125.23±0.64 cm and 111.27±0.80 cm. Transparency levels started decreasing from June and the minimum mean transparency recorded at S1, S2, S3, S4 and S5 were 76.75±1.80 cm, 79.67±1.33 cm, 82.03±0.92 cm, 83.33±0.41 cm, and 73.97±0.56 cm, respectively during August.

Transparency varied significantly ($P<0.05$) among the months and among the sites as well (Table 4.6). Water transparency of January was significantly varied ($P<0.05$) than that of other months of the year except February. Water transparency of August was significantly lower ($P<0.05$) than that of other months of the year. Similarly, water transparency of S3 was significantly higher ($P<0.05$) as compared to S1, S2, S4 and S5. Transparency displayed (Table 4.22) a significant positive correlation ($P<0.05$) with dissolved oxygen ($r= 0.8735$), alkalinity ($r= 0.1990$), hardness ($r= 0.2562$) and water pH ($r= 0.6607$) but was significantly negatively correlated ($P<0.05$) with water temperature (r= -0.4850), Total dissolved solids (r= -0.8853), free carbon dioxide (r= -0.7715), nitrate-nitrogen (r= -0.8504), and Phosphate-phosphorus (r= -0.7822).

Water transparency levels are influenced by light penetration, suspended inert particles, surface run-off and plankton diversity. Water becomes murky, during the monsoon owing to rains and surface run-off, silt and organic loads. Therefore, reducing the transparency values. Similar observations have been reported by (Singh *et al*., 2017 in two floodplain Lakes, North Bihar, India). It may have been because of the much lower rainfall and less inflowing runoff during the winter months that it initially began to improve in clarity. According to Sarkar *et al*. (2020) the range of transparency of water in floodplain wetlands in West Bengal was from 85 cm to 226 cm. Khan (2002) reported transparency in the range from 65.50 cm to 120.50 cm and 50 cm to 108 cm at Beri Gopalpur wetland and Sosadanga wetland in North 24 Parganas, West Bengal respectively. Sarkar *et al.* (2020) reported the transparency ranges from 28 cm to 58 cm in Chaltia wetland, a Gangetic floodplain wetland, situated in Murshidabad district, West Bengal. Ziauddin *et al*. (2013) observed that the average transparency varying between 1.94±0.05 m and 1.34±0.02 m in Suguna *beel* and Kole *beel* (open *beel*), West Bengal, India. In an open wetland, Puthiyottil *et al.* (2021) recorded mean transparency was 1.3±0.29 m at Katiganga wetland of Murshidabad district. According to Sarkar *et al*. (2020) three floodplain wetlands, Bhomra, Mathura and Chandania had an average water transparency of 1.23±0.43 m, 0.51±0.2 m, and 0.95±0.27 m, respectively. The present findings are in acceptable limit and is in accordance with the findings of the earlier authors as stated above.

4.1.3 Total dissolved solids (TDS)

The majority of the total dissolved solids in water are inorganic salts, with a minor portion being organic substances including carbonate, bicarbonate, chloride, sulphate, nitrate, sodium, potassium, calcium, and magnesium (Thirumalini and Joseph, 2009). Total dissolved solids (TDS) have an impact on everything that consumes, lives in, or utilises water and are directly related to the purity of water. The amount of total dissolved solids in water comes from natural sources and is influenced by location, the pond's geological nature, drainage, rainfall, bottom deposit, and inflowing water (Kaushik and Saksena, 1999). The majority of fish-rich aquatic environments can withstand TDS concentrations of up to 1000 mg/l (Boyd, 2002).

The average monthly fluctuations of TDS in the five sampling stations during the study period are presented in Table 4.5 and as well as in Figure 4.4. It was found to be in the range of 80.50±0.45 to 132.47±0.30 mg/l. From the month of March onwards it started decreasing and the lowest mean value of total dissolved solids was obtained in May with the value of 87.17±0.20 mg/l, 85.23±0.25 mg/l, and 80.50±0.45 mg/l, 83.47±0.35 mg/l and 89.77±0.49 mg/l at the site of S1, S2, S3, S4 and S5, respectively. It started increasing from June and the highest mean values of 132.47±0.30 mg/l, 124.67±0.61 mg/l, 128.10±0.26 mg/l, 131.80±0.26 mg/l and 129.33±0.57 mg/l were noticed in July across the five stations of the *beel* in monsoon season.

Total dissolved solids in water varied significantly ($P<0.05$) both among the months and of the sites during the study (Table 4.7). Total dissolved solids in water of July was significantly higher ($P<0.05$) than that of other month of the year. Total dissolved solids in water of S1 was significantly varied ($P<0.05$) from S2, S3 and S4 except S5. Total dissolved solids in water displayed (Table 4.22) a significant positive correlation ($P<0.05$) with free carbon dioxide (r= 0.7653), nitrate-nitrogen (r= 0.7274), Phosphate-phosphorus (r= 0.7317) and water temperature (r= 0.2954) but was significantly negatively correlated ($P<0.05$) with dissolved oxygen (r= -0.7628), hardness (r= -0.1183), water pH (r= -0.6513), transparency (r= -0.8853).

Total dissolved solid levels in the pre-monsoon may be lower owing to less mineralization and, in comparison, less pollutant leaching into the lake, which is consistent with findings of Mahapatra *et al*. (2011). However, the monsoon season saw the greatest levels, which may be related to the inflow of effluents from drainage units next to the *beel* and the addition of massive amounts of residential sewage water, agricultural waste, household detergent, soap, and other debris. The current result is consistent with that of the prior researcher (Laishram and Dey, 2014; Siva and John, 2016). Greater values in winter may be related to the water's significant volume of organic material decomposing. In an open wetland, Puthiyottil *et al*. (2021) recorded mean TDS was 251.35±17.02 mg/l at Katiganga wetland of Murshidabad district. Laishram and Dey (2014) reported TDS was in the range of 50-150 ppm in Loktak Lake, Manipur, India. The result of the present study is quite similar to the finding of the above authors. It is also in agreement with the findings of other researchers (Patra *et al*., 2010; Miraj and Bhattacharya, 2017).

Table 4.4 Monthly variation in water transparency (cm) of Bansabati *beel*

Stations	December, 2020	January, 2021	February, 2021	March, 2021	April, 2021	May, 2021	June, 2021	July, 2021	August, 2021	September, 2021	October, 2021	November, 2021	Average
S1	98.56±0.51	113.97±1.05	115.40±1.27	107.43±1.25	109.83±1.75	103.33±1.15	100.93±0.45	81.23±1.91	76.75±1.80	79.03±0.61	90.27±2.63	98.63±2.51	97.95
S2	114.77±0.75	119.70±0.85	119.27±0.64	112.97±0.50	111.27±0.64	106.97±0.72	106.93±0.80	87.23±0.32	79.67±1.33	82.90±0.75	93.73±1.53	104.77±0.75	103.35
S3	118.23±1.70	121.50±0.62	124.02±1.00	119.53±0.68	115.40±0.45	108.00±2.19	102.73±2.20	92.17±0.65	82.03±0.92	86.87±0.60	98.87±0.55	106.33±1.02	106.31
S4	109.93±0.51	**125.23±0.64**	120.70±1.08	116.63±0.70	110.03±0.65	111.27±0.73	103.03±0.75	94.27±0.92	83.33±0.41	84.80±1.13	96.87±0.35	102.27±0.68	104.86
S5	102.33±0.41	111.27±0.80	114.63±0.61	110.23±0.83	105.90±0.81	101.80±0.43	97.57±0.58	84.33±0.66	**73.97±0.56**	75.07±0.45	87.10±0.9	99.53±0.55	96.98

Table 4.5 Monthly variation in total dissolved solids (mg/l) of water of Bansabati *beel*

Stations	December, 2020	January, 2021	February, 2021	March, 2021	April, 2021	May, 2021	June, 2021	July, 2021	August, 2021	September, 2021	October, 2021	November, 2021	Average
S1	97.53±0.50	98.57±0.49	97.37±0.47	92.10±0.65	95.60±0.60	87.17±0.20	110.63±0.40	**132.47±0.30**	128.83±0.37	116.27±0.37	114.00±0.80	105.27±0.64	106.317
S2	91.43±0.51	92.33±0.57	96.37±0.40	86.07±0.60	89.03±0.15	85.23±0.25	106.27±0.30	124.67±0.61	131.90±0.79	110.23±1.36	112.83±0.76	109.40±0.60	102.981
S3	87.27±0.37	85.53±0.83	92.47±0.50	84.03±0.15	85.10±0.17	**80.50±0.45**	103.13±1.25	128.10±0.26	122.90±0.36	119.60±0.45	102.63±0.40	98.63±0.45	99.158
S4	92.10±0.65	93.57±1.06	94.33±0.41	89.57±0.45	91.73±0.64	83.47±0.35	99.33±0.35	131.80±0.26	124.73±0.37	121.57±0.45	111.87±0.60	101.80±0.36	102.989
S5	95.57±0.51	96.60±0.52	98.17±0.15	90.33±0.57	97.67±0.35	89.77±0.49	109.13±0.32	129.33±0.57	125.93±0.30	122.00±1.00	113.33±0.41	103.07±0.20	105.908

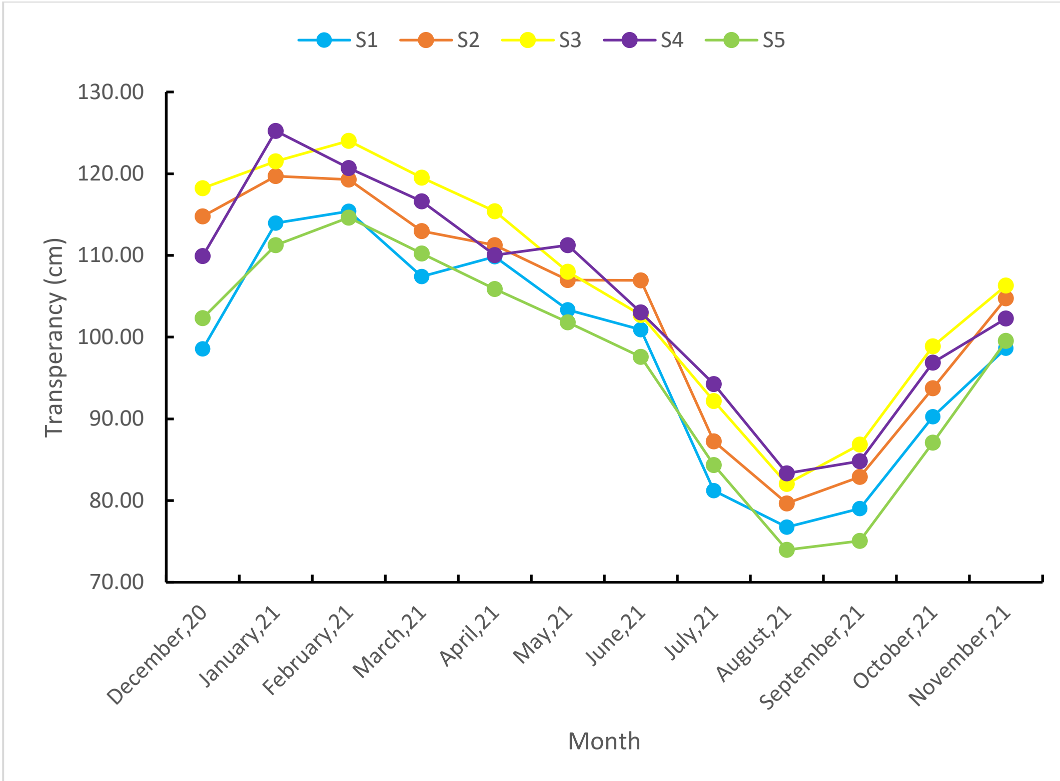


Figure 4.3 Monthly variation in water transparency (cm) of Bansabati *beel*

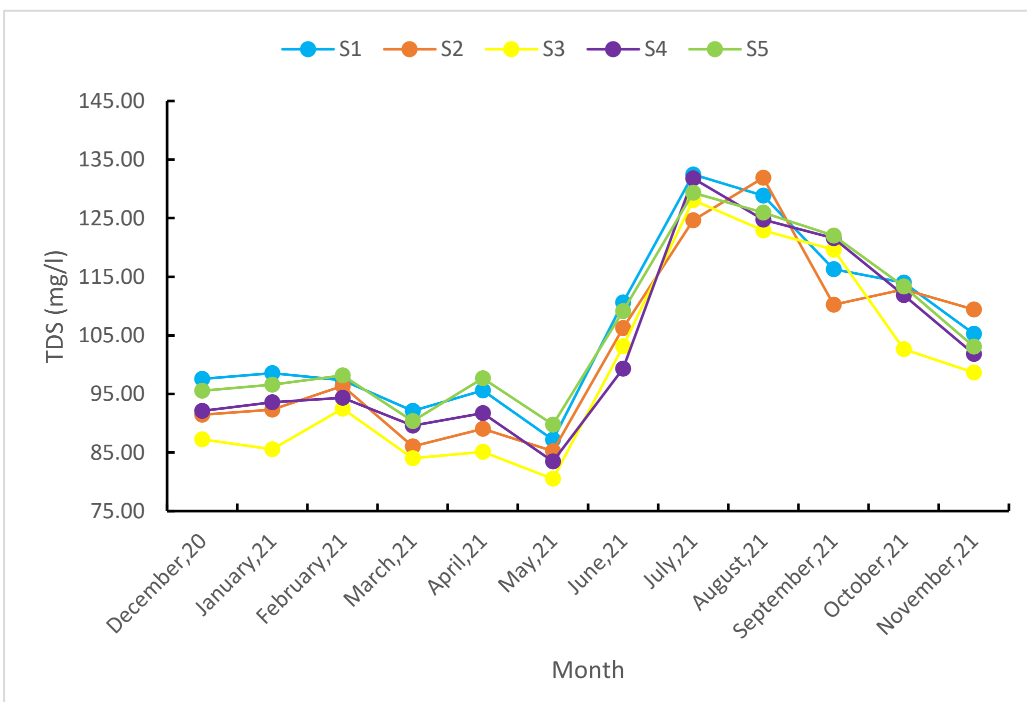


Figure 4.4 Monthly variation in total dissolved solids (mg/l) of Bansabati *beel*

Table 4.6 Two way ANOVA (with replication) to analyse month wise and station wise variation of water transparency of Bansabati *beel*

Source	Sum of Squares	DF	Mean Square	F	P
Months	30328.610	11	2757.146	1169.645	<0.001
Stations	2525.748	4	631.437	267.870	<0.001
Months*Stations	785.770	44	17.858	7.576	<0.001
Residual	282.870	120	2.357		

Table 4.7 Two way ANOVA (with replication) to analyse month wise and station wise variation of total dissolved solids of water of Bansabati *beel*

Source	Sum of Squares	DF	Mean Square	F	P
Months	37212.806	11	3382.982	1987.586	<0.001
Stations	998.217	4	249.554	146.619	<0.001
Months*Stations	1157.633	44	26.310	15.458	<0.001
Residual	204.247	120	1.702		

4.1.4 Water pH

pH, the potential of hydrogen ion concentration is a scale to denote acidity or basicity of a solution, is not only controls majority of biological and biochemical reactions in water, but also many enzymatic reactions within the body of an organism. Aquatic creatures are harmed by pH levels that are excessively low and high. A flourishing aquatic life is supported by a pH range of 6.7 to 8.4. (Dallas and Day, 2004). The results of pH at monthly intervals are presented in Table 4.8 and as well as in Figure 4.5.

The average pH value during the present study was with the range of 7.28 to 8.09, indicating that the water of Bansabati *beel* was almost sub alkaline to alkaline and supports fairly good aquatic productivity. The alkaline pH observed during the present study may be due to the cumulative effect of macrophytes, environmental and biological factors (Reid and Mosley, 2016).

The lowest mean value of pH in July was 7.25, 7.27, 7.39, 7.31, and 7.21 at S1, S2, S3, S4 and S5 respectively, in the Bansabati *beel*, in monsoon season, which may be due to heavy rainfall and frequent flooding in the area (Sanderson *et al.*, 2005). It started increasing from September onwards and the highest mean value of pH was observed as

8.02, 8.04, 8.15, 8.23 and 8.02 at S1, S2, S3, S4 and S5, respectively during February with a sharp decline in March.

There existed a significant difference ($P<0.05$) in pH values among the months and among the sites during the present study (Table 4.10). Water pH value of January was significantly varied ($P<0.05$) from the other month of the year except February. Water pH value of S3 was significantly varied from S1, S2, S4 and S5. The pH value of water displayed (Table 4.22) a significant positive correlation ($P<0.05$) with dissolved oxygen (r= 0.7683), hardness (r= 0.6624), transparency (r= 0.6607), alkalinity (r= 0.5816) but was significantly negatively correlated ($P<0.05$) with phosphate-phosphorus (r= -0.8680), water temperature (r= -0.6365), TDS (r= -0.6513), free carbon dioxide (r= -0.8561) and nitrate-nitrogen (r= -0.7369).

The stirring action of incoming water, increased microbial respiration that releases carbon dioxide into the water, and the breakdown of macrophytes that releases carbon dioxide into the water are all potential causes of the pH value dropping during the monsoon (Blum, 1957; Swingle, 1961; Blum, 2011). This concurs with the present study as well as viewpoints expressed by Meetei and Singh (2011). The fact that the pH was at its maximum in the winter may be attributed to algae and other aquatic plants that use carbon dioxide from the atmosphere during photosynthesis to increase pH.

According to Sarkar *et al*. (2020) the range of dissolved oxygen of water in floodplain wetlands in West Bengal was from 6.8 to 9.7. In an open wetland, Puthiyottil *et al.* (2021) recorded mean pH was 7.84±0.42 at Katiganga wetland of Murshidabad district. According to Sarkar *et al*. (2020) three floodplain wetlands, Bhomra, Mathura and Chandania had an average water pH of 7.93±0.63, 8.86±0.61, 7.99±0.38 respectively. Sarkar *et al.* (2020) reported the pH range from 7.8 to 8.3 in Chaltia wetland, a gangetic floodplain wetland, situated in Murshidabad district, West Bengal. Panigrahi *et al*. (2014) observed that the pH of the Kalyani Lake, West Bengal ranges from 7.16 to 8.37 showing little alkaline nature. Singh *et al*. (2017) reported that the average pH was from 7.2 to 8.2 at Bhara Haripota *beel* in Bhamanghata, South 24 Parganas district of West Bengal. Ghosh and Biswas (2018) recorded the mean value of pH of Chhariganga oxbow lake in Nadia district, West Bengal as 8.17. The present findings are in concurrence with the findings of the above researchers.

4.1.5 Dissolved oxygen (DO)

The two main sources of oxygen in water are atmospheric air and planktons that engage in photosynthetic processes. It is much harder for aquatic organisms than it is for terrestrial species to obtain enough oxygen because of the low solubility of oxygen in water, which also decreases with increased temperature, increased salinity, low atmospheric pressure, high humidity, high concentrations of submerged plants, and plankton blooms. Oxygen depletion in water causes fish feeding and starvation, stunted development, and increased fish death, either directly or indirectly (Bhatnagar and Devi, 2013). Dissolved oxygen has an impact on the physiology, behaviour, distribution, and growth of fish, shrimp, and other aquatic organisms (Solis, 1988). In general, several species die when the amount of dissolved oxygen drops below 3 mg/l (Boyd, 1990). The development of aquatic organisms is favoured by water that has oxygen level more than 5 mg/l (McNeely *et al*., 1979). The results of dissolved oxygen (DO) at monthly intervals are presented in Table 4.9 and as well as in Figure 4.6.

The average dissolved oxygen observed during the study period was 5.49 mg/l. The dissolved oxygen fluctuated between 4.04±0.03 mg/l (S5 during July) and 6.90±0.02 mg/l (S4 in December). The obtained range of dissolved oxygen is similar to those Ziauddin *et al*. (2013); Miraj and Bhattacharya (2017); Sarkar *et al*. (2020) and Puthiyottil *et al*. (2021).

The minimum dissolved oxygen at S1, S2, S3, S4 and S5 were 4.11±0.01 mg/l, 4.22±0.01 mg/l, and 4.34±0.01 mg/l, 4.05±0.02 mg/l and 4.20±0.04 mg/l during August. Thereafter it showed an increasing trend from September and the mean maximum dissolved oxygen observed at S1, S2, S3, S4 and S5 as 6.64±0.02 mg/l, 6.74±0.01 mg/l, 6.87±0.00 mg/l, 6.90±0.02 mg/l and 6.61±0.02 mg/l during December. The DO levels, however shown a sudden drop in April.

Dissolved oxygen water bodies varied significantly ($P<0.05$) among the months as well as among the sites (Table 4.11). DO content of August was significantly varied ($P<0.05$) from the other months of the year except July. Dissolved oxygen of water value of S3 was significantly varied from S1, S2, and S5 except S4. DO content of water displayed (Table 4.22) a significant positive correlation ($P<0.05$) with hardness (r= 0.6261), transparency (r= 0.8735), alkalinity (r= 0.4977), water pH (r= 0.7683) but was significantly negatively correlated ($P<0.05$) with phosphate-phosphorus (r= -0.9015), water temperature (r= -0.7867), TDS (r= -0.7628), free carbon dioxide (r= -0.8842), nitrate-nitrogen (r= -0.9609).

According to Sarkar *et al*. (2020) the range of dissolved oxygen of water in floodplain wetlands in West Bengal was from 3.2 mg/l to 12.5 mg/l. in an open wetland, Puthiyottil *et al*. (2021) recorded mean dissolved oxygen in water was 5.67±1.20 mg/l at Katiganga wetland of Murshidabad district. Further, Sarkar *et al*. (2020) reported the dissolved oxygen range from 2.34 to 10.2 mg/l in Chaltia wetland, a gangetic floodplain wetland, situated in Murshidabad district, West Bengal.

Due to water's diminished capacity to store more oxygen at higher temperatures (Wetzel, 2001), a downward trend in the oxygen level of water was observed during the summer. This might also be the result of an increase in organic waste, agricultural runoff, and sewage, which decomposes more quickly at higher temperatures and lowers the oxygen content of water (Deacutis, 2016). Lower values in monsoon can be attributed to gloomy weather and greater temperature and also the usage of oxygen for metabolic activities of aquatic biota which devoured oxygen from water. A similar variation was reported by Das *et al*. (2012); Mondal *et al*. (2010) and Singh *et al*. (2017). Further, floating aquatic vegetation and pit formation in the *beel* could also lower the DO level in monsoon (Hazarika *et al*., 2013). Higher values in post-monsoon compared with monsoon, might be due to the high phytoplankton population as opined by Majumder *et al*. (2015). However, DO was found to be greater in the winter season and low in the pre-monsoon season. Dissolved oxygen was reported higher in the winter season possibly owing to greater transparency and lower water temperature which is as a consequence of increased solubility of oxygen, which, in turn, enhancing photosynthetic activity by algae and other aquatic plants, thereby rising oxygen levels in water (Kosygin *et al*., 2007; Kangabam *et al*., 2017). It is also supported by our study that negative correlation value with water temperature and positive correlation with transparency.

Table 4.8 Monthly variation in water pH of Bansabati *beel*

Stations	December, 2020	January, 2021	February, 2021	March, 2021	April, 2021	May, 2021	June, 2021	July, 2021	August, 2021	September, 2021	October, 2021	November, 2021	Average
S1	7.81±0.00	7.92±0.00	8.02±0.00	7.60±0.00	7.73±0.00	7.63±0.00	7.15±0.00	7.25±0.00	7.23±0.00	7.74±0.00	7.78±0.00	7.86±0.00	7.64
S2	7.87±0.00	8.04±0.00	8.04±0.00	7.71±0.00	7.75±0.00	7.74±0.00	7.27±0.00	7.27±0.00	7.35±0.00	7.79±0.00	7.88±0.00	7.87±0.00	7.71
S3	7.95±0.00	**8.26±0.00**	8.15±0.00	7.82±0.00	7.86±0.00	7.96±0.00	7.58±0.00	7.39±0.00	7.42±0.00	7.80±0.00	7.92±0.00	7.94±0.00	7.83
S4	7.86±0.00	8.15±0.00	8.23±0.00	7.81±0.00	7.81±0.00	7.85±0.00	7.66±0.00	7.31±0.00	7.34±0.00	7.88±0.00	7.96±0.00	7.78±0.00	7.80
S5	7.73±0.00	8.03±0.00	8.02±0.00	7.65±0.00	7.70±0.00	7.67±0.00	7.34±0.00	**7.21±0.00**	7.32±0.00	7.70±0.00	7.79±0.00	7.82±0.00	7.66

Table 4.9 Monthly variation in dissolved oxygen (mg/l) in water of Bansabati *beel*

Stations	December, 2020	January, 2021	February, 2021	March, 2021	April, 2021	May, 2021	June, 2021	July, 2021	August, 2021	September, 2021	October, 2021	November, 2021	Average
S1	6.64±0.02	6.50±0.05	6.42±0.06	5.92±0.02	5.43±0.04	4.81±0.07	4.75±0.05	4.25±0.03	4.11±0.01	4.34±0.03	4.51±0.00	5.70±0.02	5.28
S2	6.74±0.01	6.74±0.02	6.52±0.00	6.15±0.01	5.62±0.00	4.76±0.01	4.64±0.00	4.37±0.01	4.22±0.01	4.55±0.01	4.74±0.02	5.99±0.59	5.42
S3	6.87±0.00	6.64±0.02	6.63±0.02	6.26±0.01	5.83±0.01	5.33±0.02	4.56±0.00	4.49±0.00	4.34±0.01	4.69±0.01	4.91±0.01	6.26±0.03	5.56
S4	**6.90±0.02**	6.84±0.01	6.43±0.03	5.97±0.02	5.92±0.01	5.83±0.03	4.81±0.01	4.36±0.02	4.05±0.02	4.49±0.01	5.13±0.03	5.72±0.01	5.53
S5	6.61±0.02	6.72±0.02	6.32±0.02	5.84±0.01	5.22±0.00	4.80±0.02	4.69±0.03	**4.04±0.03**	4.20±0.04	4.30±0.01	4.62±0.02	5.85±0.03	5.26

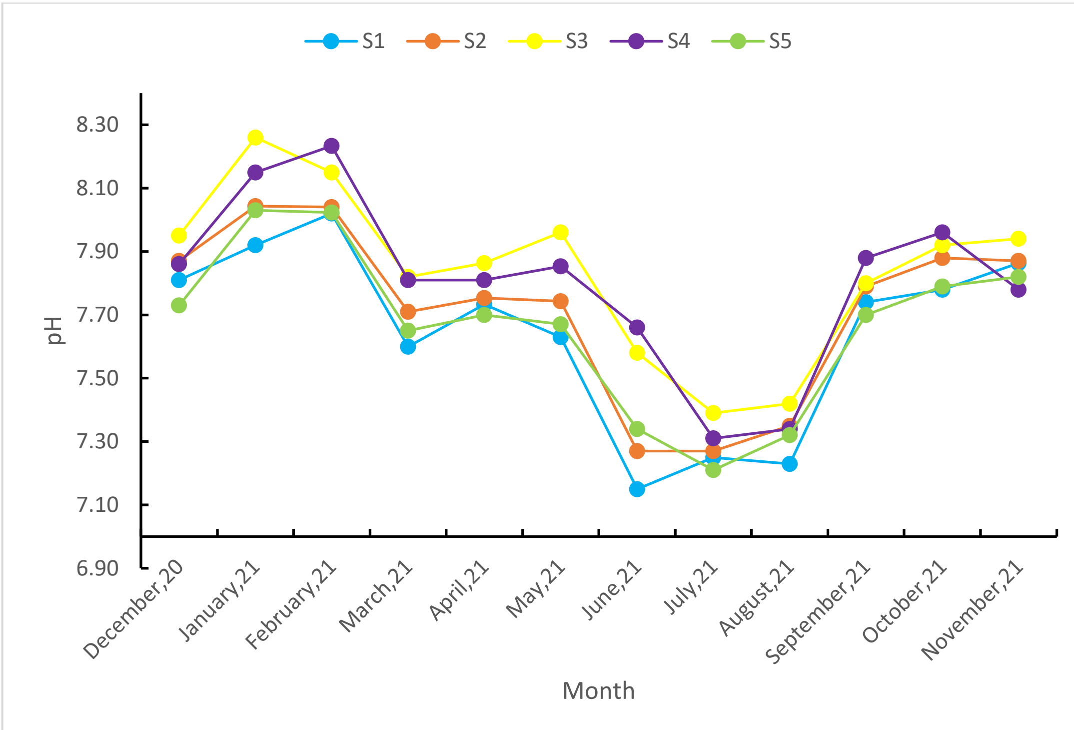


Figure 4.5 Monthly variation in water pH of Bansabati *beel*

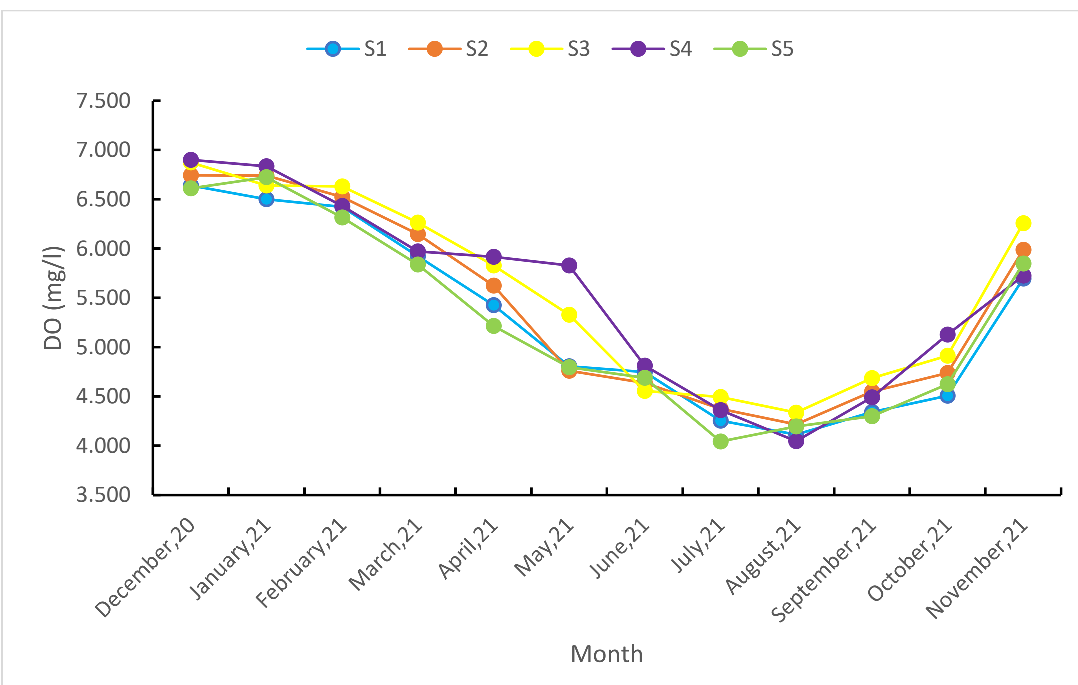


Figure 4.6 Monthly variation in dissolved oxygen (mg/l) in water of Bansabati *beel*

Table 4.10 Two way ANOVA (with replication) to analyse month wise and station wise variation of water pH of Bansabati *beel*

Source	Sum of Squares	DF	Mean Square	F	P
Months	11.577	11	1.052	1747.676	<0.001
Stations	1.029	4	0.257	427.315	<0.001
Months*Stations	0.561	44	0.0128	21.189	<0.001
Residual	0.0723	120	0.000602		

Table 4.11 Two way ANOVA (with replication) to analyse month wise and station wise variation of dissolved oxygen of Bansabati *beel*

Source	Sum of Squares	DF	Mean Square	F	P
Months	148.718	11	13.520	1401.101	<0.001
Stations	2.251	4	0.563	58.318	<0.001
Months*Stations	4.676	44	0.106	11.013	<0.001
Residual	1.158	120	0.00965		

4.1.6 Total alkalinity

Alkalinity is the amount of substances that alter the pH towards the alkaline side. Alkalinity value gives a sense of the amount of natural salts in the water (Gawas *et al*., 2006). It is typically provided by the salts of carbonates, bicarbonates, phosphate, nitrates, borax, silicates, etc. together with the free hydroxyl ions (Bhatnagar and Devi, 2013). The most prevalent and crucial elements of alkalinity are carbonates and bicarbonates. For optimal production, there should be at least 20 mg/l of total alkalinity (Banarjee, 1967). For fish cultivation, a total alkalinity ranging between 75 and 200 mg/l is considered to be ideal.

Monthly variations in total alkalinity are presented in Table 4.12 and in Figure 4.7. The total alkalinity fluctuated between 73.13±0.50 mg/l (April, S3) to 115.84±0.82 mg/l (January, S1) in the five stations of the *beel* during the entire period of study. The lowest mean values of alkalinity at S1, S2, S3, S4 and S5 were observed in April (79.46±0.74 mg/l, 82.14±0.46 mg/l, and 73.13±0.50 mg/l, 76.41±0.29 mg/l and 80.86±0.60 mg/l respectively) and continued to increase from May. A higher value of alkalinity was observed during the period of post-monsoon and winter compared to monsoon. The mean value of alkalinity across five sites of the *beel* reached the highest in January (115.84±0.82 mg/l, 109.11±0.80 mg/l, 111.22±0.80 mg/l, 113.99±0.64 mg/l and 112.93±0.28 mg/l).

Total alkalinity of water varied significantly ($P<0.05$) among the months as well as among the sites during the study period (Table 4.14). Water alkalinity of April was significantly varied ($P<0.05$) from the other months of the year. Similarly, water alkalinity of S3 was significantly varied from S1, S4, S5 but did not significantly vary ($P>0.05$) with S2. Water alkalinity displayed (Table 4.22) a significant positive correlation ($P<0.05$) with dissolved oxygen (r= 0.4977), hardness (r= 0.9193), transparency (r= 0.1990), water pH (r= 0.5816) but was significantly negatively correlated ($P<0.05$) with Phosphate-phosphorus (r= -0.4764), water temperature (r= -0.8386), free carbon dioxide (r= -0.4458), nitrate-nitrogen (r= -0.4826).

Bicarbonate levels may decrease during the summer (pre-monsoon) owing to their utilization as a source of carbon during photosynthesis by phytoplankton and other aquatic plants. Agarwal and Rajwar (2010) also endorse this point of view. However, a considerable increase in alkalinity was seen during the monsoon as a result of the dissolving of calcium ions from sediments that were otherwise dissolved by rain, floodwater, and the usage of detergent and soap. Meetei and Singh (2011) have reported similar findings. However, because to the addition of drainage water and nutrients from the surrounding rice field during the post-monsoon season, it progressively grew up until the winter season. The results of Srivastava *et al*. (2009) and Ayoade *et al*. (2009) were followed by this. Ghosh and Biswas (2016) observed a similar finding. Accumulation of organic matter and decay of vegetation and living things sum up to the alkalinity by raising carbonate and bicarbonate levels. The results of the current research concur with those of Patil *et al*. (2018).

According to Sarkar *et al*. (2020) the range of alkalinity of water in floodplain wetlands in West Bengal was from 27.3 mg/l to 282 mg/l. Puthiyottil *et al*. (2021) recorded mean alkalinity in water as 146.12±37.30 mg/l at Katiganga wetland, an open wetland situated in Murshidabad district of West Bengal. According to Sarkar *et al*. (2020) three floodplain wetlands, Bhomra, Mathura and Chandania had an average water alkalinity of 198.41±1.38 mg/l, 174.35±43.01 mg/l, 173.76±58.56 mg/l respectively. Sarkar *et al*. (2020) reported the alkalinity range from 229 mg/l to 304 mg/l in Chaltia wetland, a gangetic floodplain wetland, situated in Murshidabad district, West Bengal. Ziauddin *et al*. (2013) observed that alkalinity in Suguna *beel* and Kole *beel*, West Bengal, India was within the range of 117.98±5.38 mg/l to 177.99± 4.23 mg/l. Bhattacharya (2015) recorded the average value of alkalinity as 111 ± 30 mg/l in Mathura Lake, West Bengal, India. Ghosh and Biswas (2018) reported a mean value of alkalinity was 120±24.03 mg/l at Chhariganga oxbow lake in Nadia district, West Bengal, India. Thus, it appears that present findings of this study concurs with the findings of the earlier researchers, although wide range of alkalinities were noticed from earlier reports.

4.1.7 Hardness

The hardness of water is due to the compounds of calcium (Ca2+) and magnesium (Mg2+) which exist chiefly in the form of carbonate, sulfates and chlorides. Total hardness refers to the concentration of divalent metal ions in water expressed as equivalent of calcium carbonate which is usually related to total alkalinity as the anions of alkalinity and cations of hardness are normally derived from the solution of carbonate minerals (Das, 2001). It is the property of water that prevents the lather formation with soap. It has been stated that calcium plays an important role in cell division and the formation of the cell wall of phytoplankton and aquatic plants. Magnesium is helpful in chlorophyll formation and deficiency of it causes deformities in chlorophyll cell formation, i.e., chlorosis. Hence, hardness has great importance from the aquaculture point of view. The results of water hardness at monthly intervals are presented in Table 4.13 and Figure 4.8. Kannan (1991) has classified water based on hardness values in the following manner; Soft (0-60 mg/l), moderately hard (61-120 mg/l), hard (121-160 mg/l), and very hard (>180 mg/l).

According to this classification, water in the Bansabati *beel* could be placed in the category of 'moderately hard' to 'hard' water body with hardness ranging from 82.95±0.71 at S3 in May to 123.25±0.54 mg/l at S1 in January. A similar range of total hardness was reported by Panigrahi *et al*. (2014) in Kalyani Lake, West Bengal, and Bhattacharya (2015) in Mathura Lake, West Bengal. The average value of hardness observed during the study period was 105.55 mg/l, which is in the similar live reported by Panigrahi *et al*. (2014) and Ghosh and Biswas (2018) in different wetlands. The lowest mean values of hardness at S1, S2, S3, S4 and S5 were found to be 91.20±0.97 mg/l, 94.18±0.55 mg/l, 84.54±0.36 mg/l, 90.08±0.84 mg/l and 88.21±0.90 mg/l in June. It remained at low level further and started rising from August and continued before reaching highest value in December. The highest mean values of hardness at S1, S2, S3, S4 and S5 were recorded as 121.29±0.91 mg/l, 113.02±0.87 mg/l, 118.53±0.37 mg/l, 115.99±0.38 mg/l and 119.96±0.83 mg/l, respectively in December. Subsequently, the levels dropped in March. In this floodplain lake, a trend was observed among the seasons, hardness was lower during pre-monsoon than monsoon and post-monsoon and then higher in the winter season.

The hardness of water varied significantly ($P<0.05$) both among the months and the sites during the study period (Table 4.15). The hardness of water of April was significantly varied ($P<0.05$) from the other months of the year except May and June. The hardness of water of S3 was significantly varied ($P<0.05$) from S1, S4 and S5 of the study period but did not differ significantly ($p>0.05$) with S2. The hardness of water displayed (Table 4.22) a significant positive correlation ($P<0.05$) with dissolved oxygen (r= 0.6261), alkalinity (r= 0.9193), transparency (r= 0.2562), water pH (r= 0.6624) but was significantly negatively correlated ($P<0.05$) with phosphate-phosphorus (r= -0.6539) and water temperature (r= -0.9179), free carbon dioxide (r= -0.6407) nitrate-nitrogen (r= -0.6492).

According to Sarkar *et al*. (2020) the range of hardness of water in floodplain wetlands in West Bengal was from 16 mg/l to 208 mg/l. Sarkar *et al*. (2020) reported three floodplain wetlands in West Bengal namely, Bhomra, Mathura and Chandania had an average water hardness of 173.60±42.01 mg/l, 155.25±41.93 mg/l, and 245.12±58.50 mg/l respectively. Sarkar *et al*. (2020) reported the hardness range from 224 mg/l to 250 mg/l in Chaltia wetland, a gangetic floodplain wetland, situated in Murshidabad district, West Bengal.

The lowest value of total hardness was observed during the summer season (April) because of the low volume of water and it being absorbed by a high rate of vegetation and many organisms in the wetland. The present findings are in the agreement with the earlier views (Mishra *et al*., 2014; Sarkar *et al*., 2020). However, in the post-monsoon season, hardness values were elevated probably due to inflow of sewage, drainage water, fertilizers from the nearby agriculture field, and regular addition of large quantities of detergents used by nearby residential localities which drains into the *beel*, which might have also contributed to the increase of hardness. The earlier authors of Udhayakumar *et al*. (2006); Mohanta and Patra (2000), Devi *et al*. (2016) also recorded the similar observations while studying in different wetlands of India. Gradually increment from post-monsoon season up to winter season may also be ascribed to leaching of salts from the catchment area. A similar observation was reported by Ghosh and Biswas (2016); Roy and Hassan (2016).

Table 4.12 Monthly variation in total alkalinity (mg/l) of water of Bansabati *beel*

Stations	December, 2020	January, 2021	February, 2021	March, 2021	April, 2021	May, 2021	June, 2021	July, 2021	August, 2021	September, 2021	October, 2021	November, 2021	Average
S1	107.10±0.75	**115.84±0.82**	112.75±1.06	94.33±1.26	79.46±0.74	84.11±0.24	91.80±0.67	93.92±0.71	97.66±0.42	95.38±0.38	100.71±0/43	104.95±0.63	98.16
S2	104.72±0.36	109.11±0.80	108.96±0.73	76.75±0.53	82.14±0.46	79.82±0.27	86.38±0.59	87.18±0.59	94.14±0.84	93.34±0.74	97.25±0.59	99.16±0.61	93.24
S3	100.93±0.58	111.22±0.80	105.23±0.67	80.94±0.58	**73.13±0.50**	82.65±0.21	82.06±0.76	84.29±0.43	90.30±0.44	100.93±0.48	95.21±0.41	101.23±0.66	92.34
S4	98.73±0.61	113.99±0.64	113.44±0.44	85.73±0.65	76.41±0.29	81.74±0.46	85.35±0.64	90.92±0.30	92.78±0.20	97.74±0.54	99.60±0.34	102.43±0.08	94.90
S5	105.54±0.36	112.93±0.28	110.02±0.58	89.57±0.37	80.86±0.60	92.55±0.33	89.55±0.42	95.52±0.33	95.80±0.57	98.92±0.46	98.46±0.28	98.49±0.27	97.35

Table 4.13 Monthly variation in total hardness (mg/l) of water of Bansabati *beel*

Stations	December, 2020	January, 2021	February, 2021	March, 2021	April, 2021	May, 2021	June, 2021	July, 2021	August, 2021	September, 2021	October, 2021	November, 2021	Average
S1	121.29±0.91	**123.25±0.54**	113.34±0.63	95.21±0.58	89.11±0.58	88.23±0.72	91.20±0.97	95.28±0.36	98.63±0.23	104.29±0.50	110.47±0.39	113.54±0.29	103.65
S2	113.02±0.87	117.09±0.56	109.33±0.29	91.00±0.77	84.34±0.61	85.44±0.25	94.18±0.55	89.50±0.42	93.56±0.27	98.33±0.65	103.20±0.71	109.38±0.79	99.03
S3	118.53±0.37	110.11±0.76	104.22±0.86	98.18±0.46	86.08±0.74	**82.95±0.71**	84.54±0.36	91.76±0.45	91.06±0.86	101.12±0.27	105.85±0.78	107.28±0.68	98.47
S4	115.99±0.38	112.11±1.03	110.37±0.75	90.33±0.83	91.19±0.68	90.99±0.75	90.08±0.84	93.25±0.74	97.20±0.60	106.03±0.67	109.05±1.01	103.32±0.93	100.82
S5	119.96±0.83	120.62±1.00	108.99±0.83	93.75±0.43	92.87±0.96	93.08±0.70	88.21±0.90	90.89±0.44	100.07±0.79	103.38±0.57	107.47±1.04	111.79±0.54	102.59

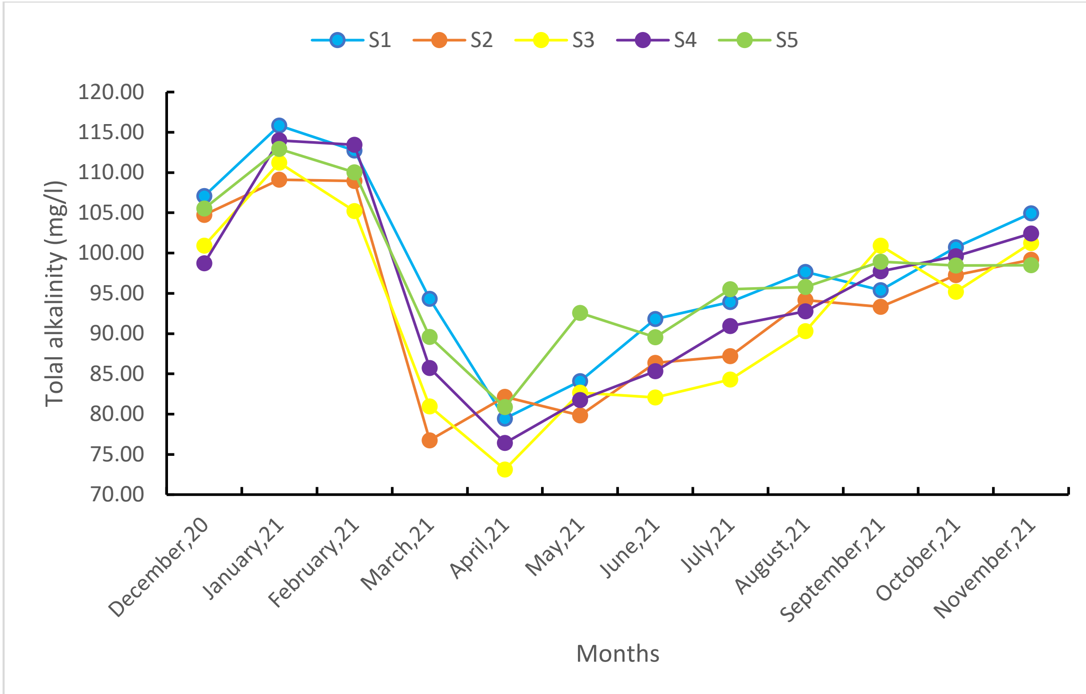


Figure 4.7 Monthly variation in total alkalinity (mg/l) of water of Bansabati *beel*

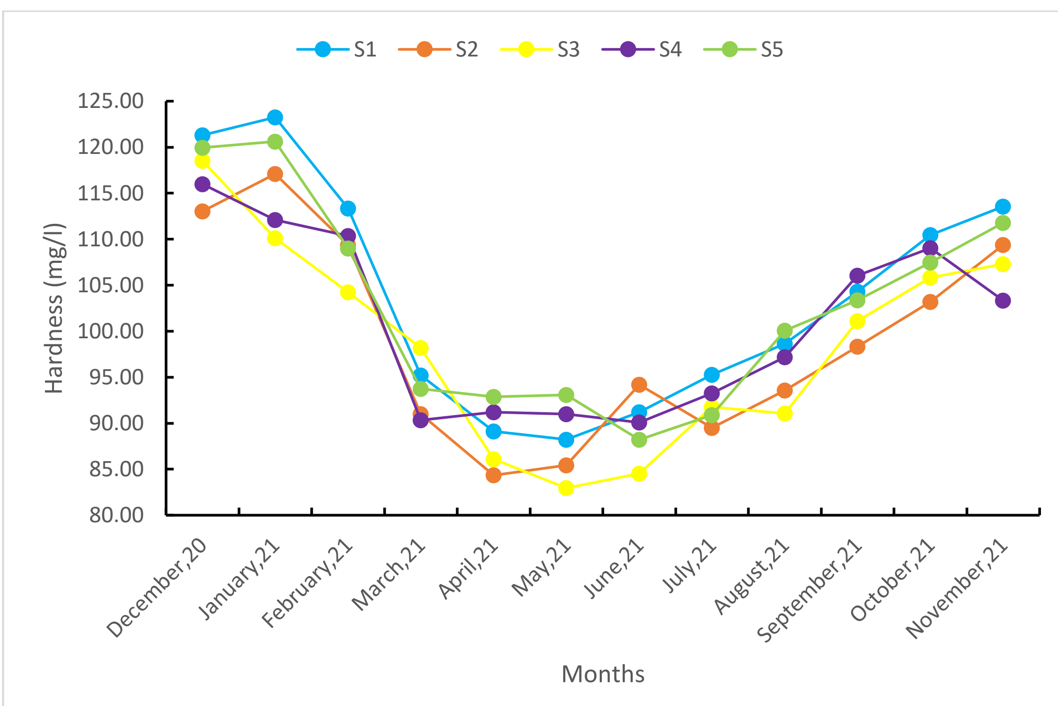


Figure 4.8 Monthly variation in total hardness (mg/l) of water of Bansabati *beel*

Table 4.14 Two way ANOVA (with replication) to analyse month wise and station wise variation of alkalinity of Bansabati *beel*

Source	Sum of Squares	DF	Mean Square	F	P
Months	18500.080	11	1681.825	816.673	<0.001
Stations	917.286	4	229.321	111.356	<0.001
Months*Stations	1224.806	44	27.837	13.517	<0.001
Residual	247.123	120	2.059		

Table 4.15 Two way ANOVA (with replication) to analyse month wise and station wise variation of hardness of Bansabati *beel*

Source	Sum of Squares	DF	Mean Square	F	P
Months	19508.929	11	1773.539	1024.039	<0.001
Stations	710.728	4	177.682	102.593	<0.001
Months*Stations	1140.776	44	25.927	14.970	<0.001
Residual	207.829	120	1.732		

4.1.8 Free carbon dioxide

Free carbon dioxide, a highly soluble gas in water, is the main source of carbon pathway in the nature. It is contributed by the respiratory activity of animals and can exist in water as bicarbonate or carbonates in the dissolved or bound form in earth crust. It greatly influences the pH level in the water (Boyd, 1979). According to Ekubo and Abowei (2011) tropical fish can tolerate carbon dioxide levels over 100 mg/l, but the ideal level of carbon dioxide in fishponds is <10 mg/l (Santhosh and Singh, 2007). Bhatnagar *et al*. (2004) suggested 5-8 mg/l is essential for photosynthetic activity; 12-15 mg/l is sub lethal to fish and 50-60 mg/l is lethal to fish. However, Boyd and Lichtkoppler (1979) was of the opinion that fish can survive up to 60 mg/l free carbon dioxide concentration.

The results of free carbon dioxide in water at monthly intervals are presented in Table 4.16 and in Figure 4.9. These results fluctuated between 4.30±0.00 mg/l at S3 in December to 9.31±0.02 mg/l at S1 in August in the five stations of the *beel*. The lowest mean value of free carbon dioxide at S1, S2, S3, S4 and S5 were found to be 4.72±0.01 mg/l, 5.06±0.01 mg/l, 4.30±0.00 mg/l, 4.91±0.01 mg/l and 5.02±0.01 mg/l in December. Thereafter, the levels started increasing from January and reached their highest values in

August. The highest mean values of free carbon dioxide at S1, S2, S3, S4 and S5 were observed as 9.31±0.02 mg/l, 9.02±0.03 mg/l, 8.43±0.01 mg/l, 7.97±0.01 mg/l and 9.17±0.01 mg/l in August respectively. So, it was concluded that the free carbon dioxide of water in the Bansabati *beel* was in ideal range suggested for fish growth and survival.

Free Carbon dioxide of water varied significantly ($P<0.05$) among the months as well as among the sites (Table 4.18). Free Carbon dioxide of water of December was significantly varied ($P<0.05$) than that of other month of the year. Free Carbon dioxide of water of S1 significantly differ ($P<0.05$) from other site (S2, S3, S4 and S5) of the study period. Free Carbon dioxide of water displayed (Table 4.22) a significant positive correlation ($P<0.05$) with Phosphate phosphorus (r= 0.9488), water temperature (r= 0.6660), nitrate-nitrogen (r= 0.9336), TDS (r= 0.7653) but was significantly negatively correlated ($P<0.05$) with transparency (r= -0.7715), water pH (r= -0.8561), dissolved oxygen (r= -0.8842), alkalinity (r= -0.4458) and hardness (r= -0.6407).

According to Sarkar *et al*. (2020) three floodplain wetlands, Bhomra, Mathura and Chandania had an average free water carbon dioxide of 5.23±0.04 mg/l, 6.77±5.41 mg/l, 7.42±3.36 mg/l respectively. The observed high free carbon dioxide in site S1 during the month of August might be due to decomposition of wastes generated by large quantities of organic matter added to this wetland. The surface run-off of the decayed materials from agricultural land surrounding the *beel* during monsoon and the photosynthesis of the dense submerged weed might have caused the fairly high content of free carbon dioxide in *beel*.

4.1.9 Nitrate-N (NO3-N)

Nitrogen is a major constituent of protein and occupies a predominant place in aquatic ecosystem (Manna, 2008). Nitrates have been identified as the growth-limiting nutrient for photosynthetic autotrophs. The presence of nitrate in any aquatic ecosystem depends on the activity of nitrifying bacteria. In natural water, nitrogen is found as nitrate, which is the most stable form. Nitrogen enters into wetland water via human and animal wastes and runoff from agricultural lands (Murthuzasab *et al.*, 2010). It plays a key role in deciding the productivity of the aquatic ecosystem and accelerates the growth of algae and macrophytes. A higher value in the concentration of nitrate is harmful as it increases the growth of algal blooms which makes water unsuitable for use. According to Kumar and Ravindranath (1998), nitrate concentration of more than 5 mg/l in water usually indicates pollution made by human and animal wastes or fertilizer runoff. Nitrate is not acute toxic to aquatic animals even in large concentrations but the higher concentration may lead to inability to swim and reduced movement and it's favourable range is 0.1 mg/l to 4.5 mg/l in aquatic systems (Prakash, 1997).

Monthly variation in nitrate-nitrogen during the present study, is presented in Table 4.17 and Figure 4.10. The obtained range of nitrate-nitrogen, which show that the levels ranged from 0.08±0.01 mg/l to 0.37±0.01 mg/l, is lower than the range reported by Datta (2011) (range from 0.30 mg/l to 0.66 mg/l) from floodplain wetlands of India. The highest mean value of nitrate-nitrogen at S1, S2, S3, S4 and S5 were 0.37±0.01 mg/l, 0.36±0.04 mg/l, 0.32±0.02 mg/l, 0.34±0.03 mg/l and 0.35±0.01 mg/l in August. But it started decreasing from September and reached the lowest mean value in December. The values at S1, S2, S3, S4 and S5 were found to be 0.11±0.01 mg/l, 0.10±0.00 mg/l, 0.09±0.00 mg/l, 0.12±0.02 mg/l and 0.08±0.01 mg/l respectively and then suddenly increased in February.

The levels of nitrate-nitrogen in water varied significantly ($P<0.05$) among the months as well as among the sites (Table 4.19). The values of nitrate-nitrogen in water of July significantly varied ($P<0.05$) than that of other months of the year except September. Nitrate-nitrogen of water of S2 significantly differ ($P<0.05$) from other site (S1, and S5) of the study period except S3 and S4. The values of nitrate-nitrogen in water displayed (Table 4.22) a significant positive correlation ($P<0.05$) with phosphate-phosphorus (r= 0.9330), water temperature (r= 0.7721), TDS (r= 0.7274), free carbon dioxide (r= 0.9336) but was significantly negatively correlated ($P<0.05$) with transparency (r= -0.8504), water pH (r= -0.7369), dissolved oxygen (r= -0.9609), alkalinity (r= -0.4826) and hardness (r= -0.6492).

According to Sarkar *et al*. (2020) the range of nitrate-N of water in floodplain wetlands in West Bengal was from trace to 1.01 mg/l (Sugunan *et al*., 2000), which concurs the present study. Puthiyottil *et al*. (2021) recorded nitrate-nitrogen in water as 0.14±0.09 mg/l at Katiganga wetland, which was also an open wetland situated in Murshidabad district of West Bengal. According to Sarkar *et al*. (2020) three floodplain wetlands, Bhomra, Mathura and Chandania had an average nitrate-nitrogen contents of 0.105±0.04 mg/l, 0.11±0.04 mg/l, 0.06±0.04 mg/l respectively. Sarkar *et al*. (2020) further reported the nitrate-N range from 0.150 mg/l to 0.387 mg/l in Chaltia wetland, a gangetic floodplain wetland, situated in Murshidabad district, West Bengal. Thus it appear that most of wetlands studied have nitrate-nitrogen level less than 1 mg/l. During monsoon due to input of sewage, drainage water, and fertilizers which carry large amounts of nitrogen from the surrounding agricultural fields had led to the increase of nitrate. Previous authors have reported similar findings in the water bodies they studied.

But in post-monsoon, it started decreasing and it was lowest during winter probably due to its assimilation by algae and other aquatic plants as also opined by Javeed *et al*. (2019). During summer, due to low oxygen levels in the lake, it was often observed lower concentrations of nitrate in water due to increase of assimilation by algae for metabolic activities and decrease in degradation of domestic sewage, lower decaying of organic matter, and agricultural runoff (Sivakumar and Karuppasamy, 2008; Lodh *et al*., 2014).

Table 4.16 Monthly variation in free carbon dioxide (mg/l) of water of Bansabati *beel*

Stations	December, 2020	January, 2021	February, 2021	March, 2021	April, 2021	May, 2021	June, 2021	July, 2021	August, 2021	September, 2021	October, 2021	November, 2021	Average
S1	4.72±0.01	5.61±0.02	5.54±0.02	6.33±0.01	6.48±0.01	6.65±0.03	7.89±0.04	9.24±0.03	**9.31±0.02**	8.62±0.02	6.81±0.03	5.19±0.03	6.87
S2	5.06±0.01	5.03±0.01	5.92±0.01	6.26±0.01	6.87±0.01	6.64±0.02	7.99±0.02	8.97±0.02	9.02±0.03	7.45±0.02	5.88±0.01	5.04±0.02	6.68
S3	**4.30±0.00**	4.80±0.00	5.11±0.00	5.90±0.00	5.26±0.00	5.61±0.00	7.16±0.02	7.96±0.02	8.43±0.01	6.89±0.01	5.01±0.01	4.26±0.01	5.89
S4	4.91±0.01	4.82±0.01	5.12±0.01	5.92±0.01	6.04±0.01	6.04±0.01	7.08±0.02	8.56±0.01	7.97±0.01	7.51±0.01	5.37±0.02	4.72±0.04	6.17
S5	5.02±0.01	5.88±0.01	6.01±0.01	6.98±0.01	6.13±0.01	6.91±0.01	7.77±0.01	8.01±0.01	9.17±0.01	8.14±0.01	6.58±0.03	6.02±0.01	6.89

Table 4.17 Monthly variation in nitrate-nitrogen (mg/l) of water of Bansabati *beel*

Stations	December, 2020	January, 2021	February, 2021	March, 2021	April, 2021	May, 2021	June, 2021	July, 2021	August, 2021	September, 2021	October, 2021	November, 2021	Average
S1	0.11±0.01	0.14±0.01	0.18±0.02	0.21±0.02	0.24±0.02	0.29±0.02	0.29±0.00	0.33±0.02	**0.37±0.01**	0.34±0.03	0.21±0.02	0.18±0.01	0.24
S2	0.10±0.00	0.11±0.02	0.13±0.00	0.16±0.01	0.18±0.01	0.24±0.01	0.25±0.01	0.27±0.00	0.36±0.04	0.31±0.02	0.24±0.01	0.16±0.02	0.21
S3	0.09±0.00	0.10±0.00	0.15±0.01	0.14±0.01	0.21±0.00	0.22±0.00	0.21±0.02	0.29±0.04	0.32±0.02	0.30±0.01	0.18±0.02	0.13±0.01	0.20
S4	0.12±0.02	0.13±0.00	0.14±0.00	0.18±0.03	0.17±0.03	0.25±0.01	0.27±0.04	0.31±0.02	0.34±0.03	0.32±0.01	0.26±0.01	0.15±0.03	0.22
S5	**0.08±0.01**	0.12±0.01	0.17±0.01	0.19±0.00	0.25±0.01	0.28±0.02	0.26±0.01	0.30±0.01	0.35±0.01	0.33±0.02	0.23±0.04	0.17±0.01	0.23

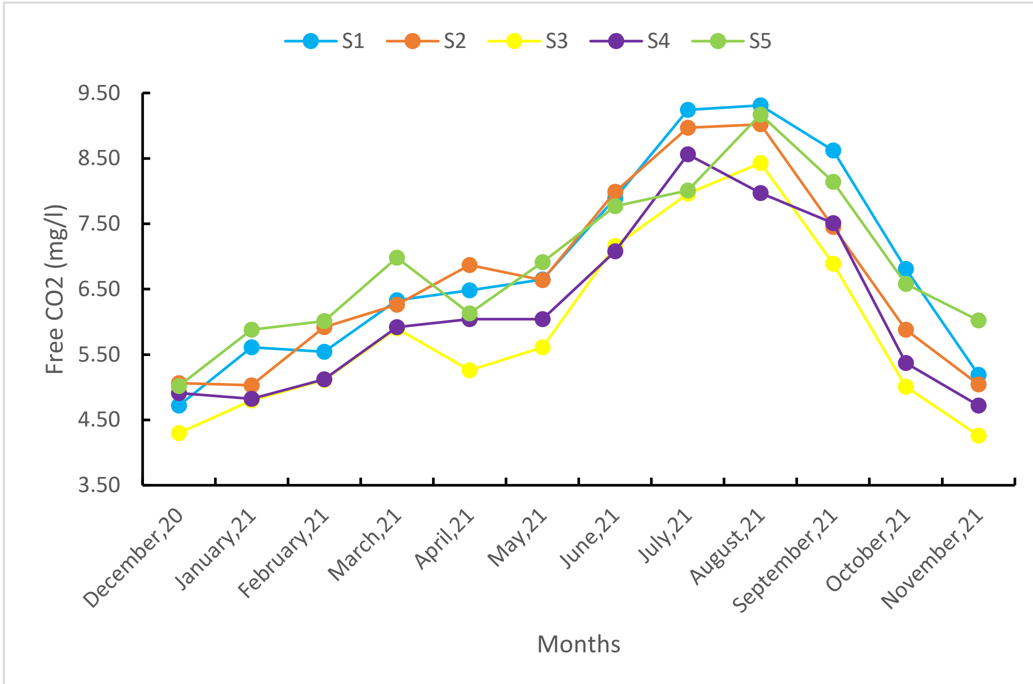


Figure 4.9 Monthly variation in free carbon dioxide (mg/l) of water of Bansabati *beel*

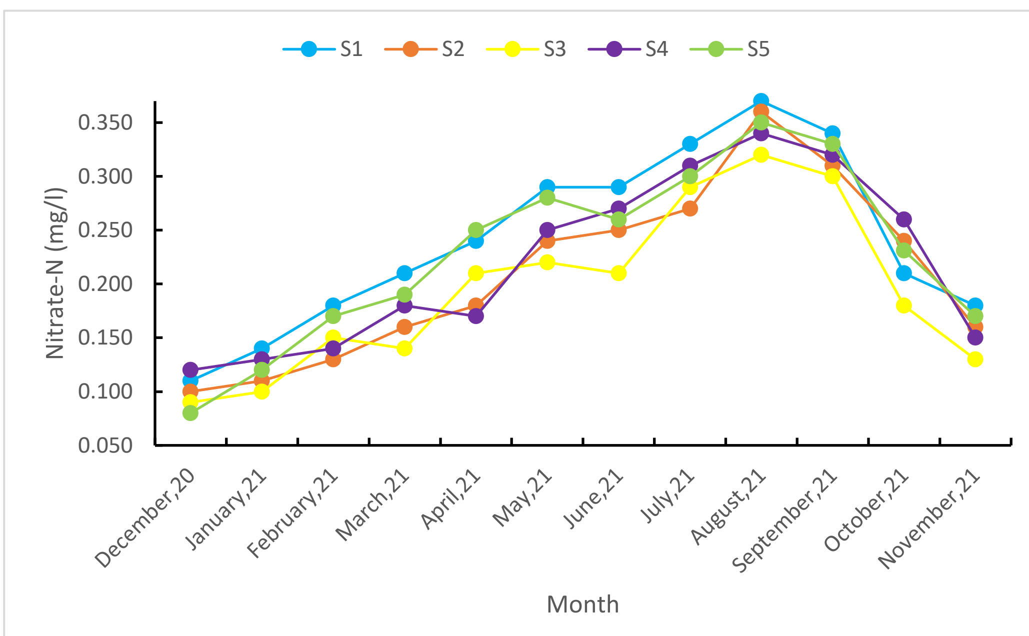


Figure 4.10 Monthly variation in nitrate-nitrogen (mg/l) of water of Bansabati *beel*

Table 4.18 Two way ANOVA (with replication) to analyse month wise and station wise variation of free carbon dioxide of Bansabati *beel*

Source	Sum of Squares	DF	Mean Square	F	P
Months	301.285	11	27.390	65213.112	<0.001
Stations	28.554	4	7.139	16996.483	<0.001
Months*Stations	15.050	44	0.342	814.392	<0.001
Residual	0.0504	120	0.000420		

Table 4.19 Two way ANOVA (with replication) to analyse month wise and station wise variation of nitrate-nitrogen of Bansabati *beel*

Source	Sum of Squares	DF	Mean Square	F	P
Months	1.056	11	0.0960	156.121	<0.001
Stations	0.0453	4	0.0113	18.427	<0.001
Months*Stations	0.0406	44	0.000923	1.500	0.044
Residual	0.0738	120	0.000615		

4.1.10 Phosphate-phosphorus (PO_4-P)

Phosphate-phosphorus is an essential nutrient for all aquatic life, but, its higher concentrations may lead to eutrophication causing water quality problems by forming algal bloom which often result in mass mortality of fish. The major source is from domestic sewage and agriculture runoff. Manna (2008) explained that phosphorus is often considered to be the most critical single element in the maintenance of aquatic productivity and its fertility ranging from 0.05 to 0.20 mg/l. in tropical waters due to high temperature, phosphate rapidly assimilates (95% within 20 minutes) by plankton and micro-organisms and hence available phosphate concentration is very low (Hayes and Phillips, 1958).

Phosphate-phosphorus is an essential plant nutrient since it is often scarce and promotes the growth of plants (algae) in addition to its role in boosting aquatic production. The values of phosphate-phosphorus at monthly intervals are ranged from 0.007±0.00 mg/l at S3 in December to 0.025±0.01 mg/l at S5 in August (Table 4.20 Figure 4.11). The obtained range of phosphate-phosphorus is lower than those reported by Panigrahi *et al*. (2014) in Kalyani Lake, West Bengal and Bhattacharya (2015) in

Mathura Lake, West Bengal, who have reported the phosphate-phosphorus in the range of 0.11-0.29 mg/l. The highest mean value of phosphate-phosphorus was recorded in August (S5: 0.025 mg/l), which started decreasing from September and reached the lowest mean value in December at S1, S2, S3, S4 and S5 were 0.011±0.00 mg/l, 0.008±0.00 mg/l, 0.007±0.00 mg/l, 0.009±0.01 mg/l and 0.010±0.01 mg/l, respectively. There was sharp increase in July.

The values of phosphate-P in water varied significantly ($P<0.05$) among the months as well as among the sites (Table 4.21). The values of phosphate-P in water of January was significantly varied ($P<0.05$) from the other months of the year except November, December and February. Phosphate-phosphorus of water of S3 significantly differ ($P<0.05$) from other site (S1, S4 and S5) of the study period except S2. The values of phosphate-phosphorus (Table 4.22) in water had a significant positive correlation ($P<0.05$) with water temperature (r= 0.6828), free CO_2 (r= 0.9488), nitrate-nitrogen (r= 0.9330) but was significantly negatively correlated ($P<0.05$) with transparency (r= -0.7822), water pH (r= -0.8680), alkalinity (r= -0.4764) and hardness (r= -0.6539).

It was highest in the monsoon season owing to the entry of domestic waste, detergent, and agricultural run-off brought a large amount of phosphorus from the agricultural field into the lake water, which is in agreement with the findings of Srinivas and Aruna (2018). But, the lowest during winter could be due to its absorption by phytoplankton and other aquatic plants as opined by Javeed *et al*. (2019). During the period of pre-monsoon, it was higher probably due to elevated temperature which augment in the rate of microbial decomposition and increases nutrient loading in sediment (Das, 2001). According to Sarkar *et al*. (2020) the range of phosphate-P of water in floodplain wetlands in West Bengal was from trace to 0.63mg/l (Sugunan *et al*., 2000). In an open wetland of Murshidabad district, Puthiyottil *et al*. (2021) recorded phosphate-P in water was 0.05±0.02mg/l at Katiganga wetland. According to Sarkar *et al*. (2020) three floodplain wetlands, Bhomra, Mathura and Chandania had an average phosphate-P of 0.029±55.02 mg/l, 0.053±0.08 mg/l, 0.08±0.10 mg/l, respectively. Sarkar *et al*. (2020) reported the higher values of the phosphate-P range from 0.180 mg/l to 0.545 mg/l in Chaltia wetland, a Gangetic floodplain wetland, situated in Murshidabad district, West Bengal.

Table 4.20 Monthly variation in phosphate-phosphorus (mg/l) of water of Bansabati *beel*

Stations	December, 2020	January, 2021	February, 2021	March, 2021	April, 2021	May, 2021	June, 2021	July, 2021	August, 2021	September, 2021	October, 2021	November, 2021	Average
S1	0.011±0.00	0.011±0.01	0.012±0.00	0.012±0.00	0.014±0.00	0.017±0.00	0.019±0.01	0.021±0.01	0.024±0.00	0.017±0.01	0.014±0.00	0.012±0.00	0.015
S2	0.008±0.00	0.009±0.00	0.008±0.01	0.013±0.00	0.015±0.00	0.014±0.00	0.017±0.00	0.019±0.00	0.021±0.00	0.014±0.00	0.011±0.00	0.009±0.00	0.013
S3	**0.007±0.00**	0.008±0.00	0.009±0.00	0.008±0.01	0.012±0.00	0.015±0.00	0.016±0.00	0.019±0.00	0.023±0.00	0.013±0.00	0.013±0.00	0.010±0.00	0.013
S4	0.009±0.01	0.009±0.00	0.010±0.01	0.009±0.00	0.011±0.00	0.016±0.00	0.017±0.00	0.023±0.00	0.022±0.01	0.016±0.00	0.012±0.00	0.008±0.00	0.014
S5	0.010±0.01	0.010±0.00	0.011±0.00	0.013±0.00	0.015±0.01	0.018±0.01	0.015±0.00	0.020±0.00	**0.025±0.01**	0.018±0.00	0.015±0.00	0.011±0.00	0.015

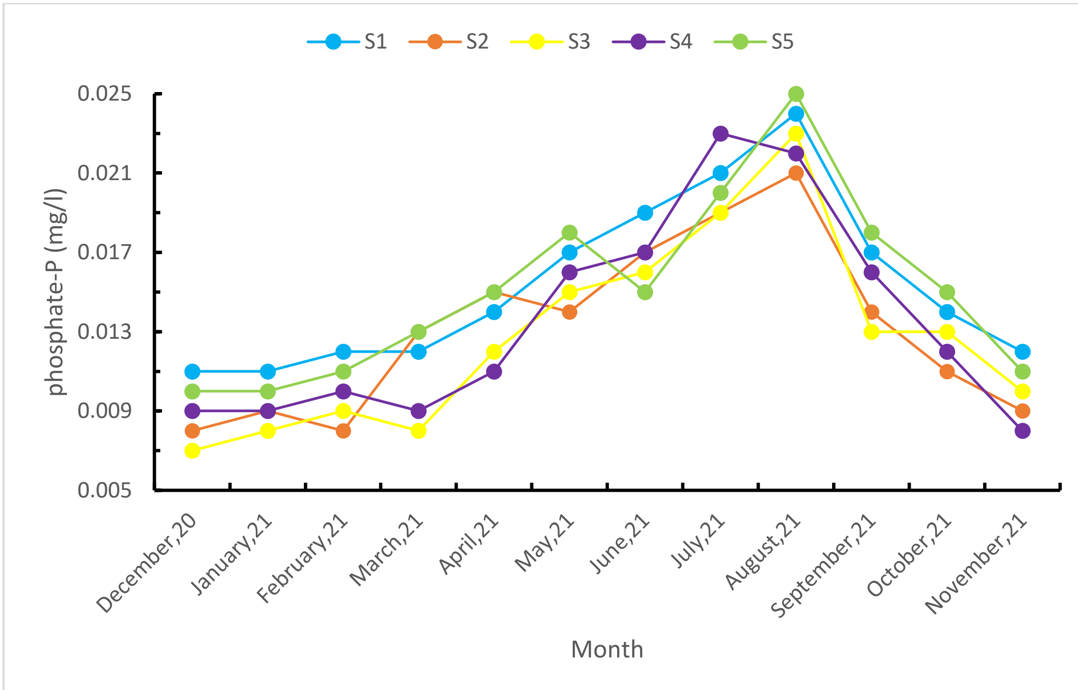


Figure 4.11 Monthly variation in phosphate-phosphorus (mg/ l) of water of Bansabati *beel*

Table 4.21 Two way ANOVA (with replication) to analyse month wise and station wise variation of phosphate-phosphorus of Bansabati *beel*

Source	Sum of Squares	DF	Mean Square	F	P
Months	0.00334	11	0.000303	540.806	<0.001
Stations	0.000183	4	0.0000457	81.460	<0.001
Months*Stations	0.000234	44	0.00000532	9.477	<0.001
Residual	0.0000673	120	0.000000561		

Table 4.22 Pearson's Correlation matrix of the selected water quality parameters of Bansabati *beel*

	Water temperature	Transparency	TDS	Water pH	DO	Alkalinity	Hardness	Free CO_2	Nitrate-N	Phosphate-p
Water temperature		-0.48504	0.29547	-0.63654	-0.78673	-0.83857	-0.91791	0.66608	0.77212	0.68286
Transparency	-0.48504		-0.88532	0.66071	0.87353	0.19909	0.25624	-0.77153	-0.8504	-0.78219
TDS	0.29547	-0.88532		-0.65128	-0.76278	0.028442	-0.11831	0.76531	0.72745	0.73171
Water pH	-0.63654	0.66071	-0.65128		0.76836	0.58168	0.66249	-0.85609	-0.73688	-0.86796
DO	-0.78673	0.87353	-0.76278	0.76836		0.4977	0.6261	-0.88422	-0.96092	-0.90151
Alkalinity	-0.83857	0.19909	0.028442	0.58168	0.4977		0.91931	-0.44577	-0.48261	-0.47642
Hardness	-0.91791	0.25624	-0.11831	0.66249	0.6261	0.91931		-0.64066	-0.64921	-0.65391
Free CO_2	0.66608	-0.77153	0.76531	-0.85609	-0.88422	-0.44577	-0.64066		0.9336	0.94884
Nitrate-N	0.77212	-0.8504	0.72745	-0.73688	-0.96092	-0.48261	-0.64921	0.9336		0.93307
phosphate-P	0.68286	-0.78219	0.73171	-0.86796	-0.90151	-0.47642	-0.65391	0.94884	0.93307	

Correlation is significant at the 0.05 level (2- tailed)

4.2 Soil parameters of the Bansabati *beel*

The quality of water in a floodplain wetland is influenced by the soil quality. It plays an important role in maintaining the productivity of the water body and can store the nutrients and release them into waters through different mechanisms under different conditions. Soil is a major component of any aquatic environment, which not only holds water for aquatic animals but also enriches the water body with the various nutrients required for biological production (Saha, 2003).

The present investigation included the study of soil sediment parameters of five stations in the Bansabati *beel* as mentioned in materials and methods. The results obtained from the study have been presented and discussed below.

4.2.1 Soil pH

Soil pH is one of the most important factors for maintaining the productivity of any water body since it controls most of the chemical reactions besides regulating water pH. Soil can be classified according to its pH value i.e. (6.5 to 7.5) is 'neutral', over 7.5 is 'alkaline' and less than 6.5 is called 'acidic'. Most of the floodplain wetlands exhibit wide variations in soil pH (4.2-8.5) in different parts of the country. But, Saha (2003) stated that the optimum pH range for sustainable aquatic life is 6.5 to 8.2. The results of soil pH recorded at monthly intervals are presented in Table 4.23 and in Figure 4.12.

Soil pH value was within the range of 6.52±0.05 to 8.11±0.05, which is well within the optimum range suggested for aquatic life and it supports good aquatic productivity too. The results of the present study correlate with the findings of Chakravarty and Patgiri (2009) where they found a pH of sediment ranging between 6.02 and 8.25. The average soil pH observed during the study period was 7.13 indicating neutral to slightly alkaline soil nature in the *beel*.

Fluctuating trends of pH in different sites of the Bansabati *beel* indicated that the minimum mean pH value at S1, S2, S3, S4 and S5 in July was 6.82±0.05, 6.64±0.05, 6.92±0.05, 6.52±0.05 and 6.74±0.05 respectively and started increasing from September and reached mean maximum value of 7.83±0.05, 7.34±0.05, 7.54±0.05, 7.91±0.05, 8.11±0.05 at S1, S2, S3, S4 and S5 respectively during January.

Two-way ANOVA (Table 4.25) indicated a significant difference ($P < 0.05$) of soil pH among the months and the stations. Soil pH of August was significantly varied ($P<0.05$) to other months of the year. Soil pH of S1 was significantly varied ($P<0.05$) from other sites (S2, S3, S4, S5) during the study period. Soil pH displayed (Table 4.30) a significant negative correlation ($P<0.05$) with total nitrogen in the soil.

Pandey *et al*. (2000) stated that soil pH was lower in monsoon and higher in the post-monsoon season, which is in agreement with the present study. It might be due to the inclusion of acidic components in wastewater into the *beel* in the monsoon season as also reported by Adhikari (2011).

Soil pH of Kalyani Lake was in the range of 6.8 to 7.09 at Nadia in West Bengal (Rout, 2010), 6.57 to 7.05 in the Dek *beel* in the Kamrup district of Assam (Gorai *et al*., 2006) and 7.12 to 7.78 in wetlands of Nadia district, West Bengal (Bala and Mukherjee, 2011) studied that the soil pH of some wetlands in Nadia district, West Bengal was within the range of 7.12-7.78. The previous studies and the present study concluded that the soil pH of wetlands under consideration is neutral to slightly alkaline.

4.2.2 Organic carbon

The availability of organic matter in the soil is due to the decomposition of plant and animal residues, living and dead microorganisms. It contributes to the soil structure, fertility, and water holding capacity (Reddy and Delaune, 2008). A good physical condition of the plants is dependent on the supply of organic constituents (nutrients) in the soil. It acts also as the source of energy for bacteria and other microbes that release nutrients through various biochemical processes (Adhikari, 2011). It plays a dominant role in maintaining the biological productivity of the aquatic ecosystem. Organic carbon in the range of 0.95-1.50% is suitable for aquaculture (Ahmed, 2004).

Organic carbon with less than 0.5% is considered to be unproductive, 0.5 – 1.5% are medium productive and 1.5-2.5% are highly productive (Ayub and Boyd, 1994; Ahmed, 2004 and Adhikari, 2011). The results of organic carbon at monthly intervals are presented in Table 4.24 and in Figure 4.13.

The values obtained in the present study ranged from 1.67±0.02% to 3.66±0.02% (mg/10 0g) productive indicating highly environment for aquaculture activities. The finding of this present study is in agreement with the findings of Das (2002) and Paul

(2003). The maximum value was observed in March 3.66±0.02 %, 3.63±0.02%, 3.57±0.02 %, 3.42±0.02% and 3.54±0.03% at S1, S2, S3, S4 and S5 respectively. In November, organic carbon showed a minimum value 1.74±0.02%, 1.85±0.02%, 1.71±0.01%, 1.67±0.02% and 1.79±0.01% at S1, S2, S3, S4 and S5 respectively.

Two-way ANOVA (Table 4.26) indicated a significant difference ($P<0.05$) of organic carbon of January month among other months except June. But there were no significant variance ($P>0.05$) among the sites. Organic carbon displayed (Table 4.30) a significant positive correlation ($P<0.05$) with total nitrogen of the soil in the study period.

Rout (2010) recorded a lower value of organic carbon percentage compare with the present study, ranging from 0.93% to 1.67% in Kalyani Lake at Nadia; West Bengal. Hajarika (2011) observed a wide range of average soil organic carbon values at Kakorikota *beel* of Majuli Island, which was within the range of 0.41 ± 0.04 % to 2.60 ± 0.04 %. But, Bala and Mukherjee (2011) observed the higher value of organic carbon of some wetlands in Nadia district, West Bengal that showed the result within the range of 2.19%-12.79%.

Table 4.23 Monthly variation in pH of soil of Bansabati *beel*

Stations	December, 2020	January, 2021	February, 2021	March, 2021	April, 2021	May, 2021	June, 2021	July, 2021	August, 2021	September, 2021	October, 2021	November, 2021	Average
S1	7.73±0.05	7.83±0.05	7.63±0.05	7.43±0.05	7.53±0.05	7.13±0.05	6.94±0.05	6.82±0.05	6.93±0.05	7.14±0.05	7.43±0.05	7.64±0.05	7.35
S2	7.23±0.05	7.34±0.05	7.13±0.05	7.03±0.05	7.24±0.05	7.04±0.05	6.83±0.05	6.64±0.05	6.73±0.05	6.93±0.05	7.34±0.05	7.43±0.05	7.07
S3	7.43±0.05	7.54±0.05	7.33±0.05	7.12±0.05	7.31±0.05	7.13±0.05	7.05±0.05	6.92±0.05	6.94±0.05	7.13±0.05	7.51±0.05	7.63±0.05	7.25
S4	7.62±0.05	7.91±0.05	7.72±0.05	7.34±0.05	7.13±0.05	7.02±0.05	6.74±0.05	**6.52±0.05**	6.71±0.05	6.83±0.05	7.22±0.05	7.53±0.05	7.20
S5	7.93±0.05	**8.11±0.05**	7.82±0.05	7.54±0.05	7.63±0.05	7.32±0.05	7.13±0.05	6.74±0.05	6.82±0.05	7.04±0.05	7.43±0.05	7.72±0.05	7.17

Table 4.24 Monthly variation in organic carbon (%) of soil of Bansabati *beel*

Stations	December, 2020	January, 2021	February, 2021	March, 2021	April, 2021	May, 2021	June, 2021	July, 2021	August, 2021	September, 2021	October, 2021	November, 2021	Average
S1	2.06±0.03	2.64±0.03	2.93±0.01	**3.66±0.02**	3.03±0.02	2.92±0.01	2.67±0.02	2.46±0.02	2.41±0.01	2.14±0.02	2.10±0.01	1.74±0.02	2.56
S2	2.15±0.04	2.75±0.02	3.05±0.03	3.63±0.02	3.08±0.01	2.92±0.01	2.73±0.02	2.35±0.03	2.31±0.02	2.2±0.02	2.1±0.02	1.85±0.02	2.59
S3	2.33±0.02	2.83±0.03	3.12±0.02	3.57±0.02	3.02±0.02	2.97±0.02	2.74±0.03	2.53±0.02	2.44±0.02	2.23±0.02	2.12±0.02	1.71±0.01	2.64
S4	2.24±0.03	2.81±0.02	3.11±0.01	3.42±0.02	3.07±0.02	2.85±0.02	2.65±0.01	2.56±0.01	2.44±0.03	2.25±0.01	1.80±0.57	**1.67±0.02**	2.57
S5	2.27±0.02	2.78±0.02	3.02±0.02	3.54±0.03	3.01±0.01	2.91±0.01	2.72±0.02	2.51±0.01	2.40±0.01	2.16±0.01	2.12±0.02	1.79±0.01	2.60

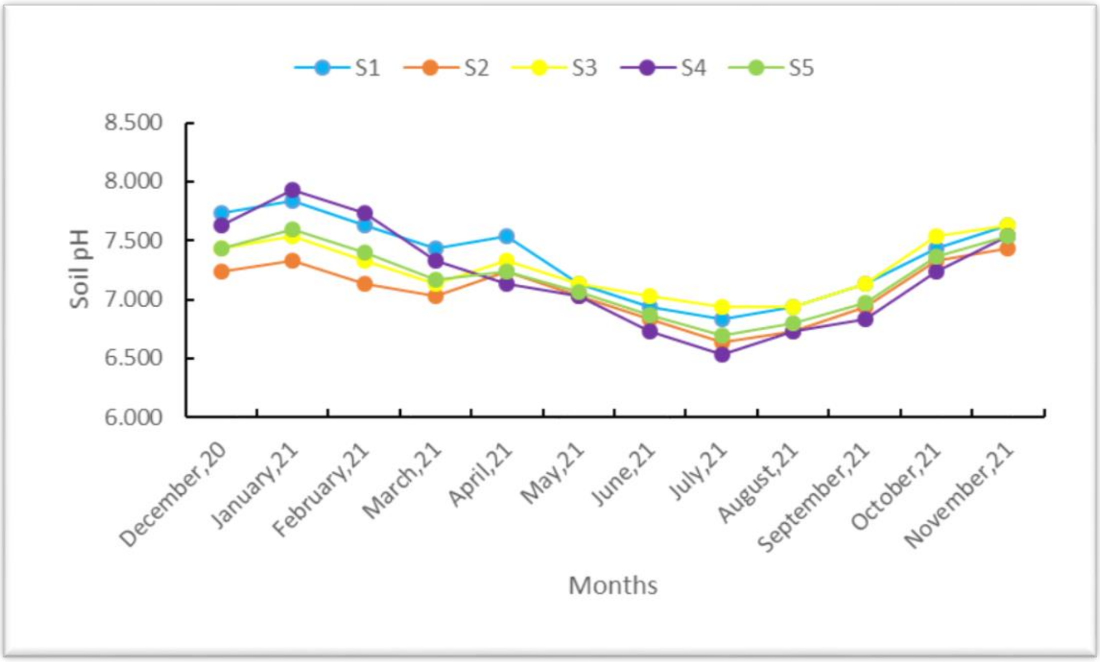


Figure 4.12 Monthly variation in pH of soil of Bansabati *beel*

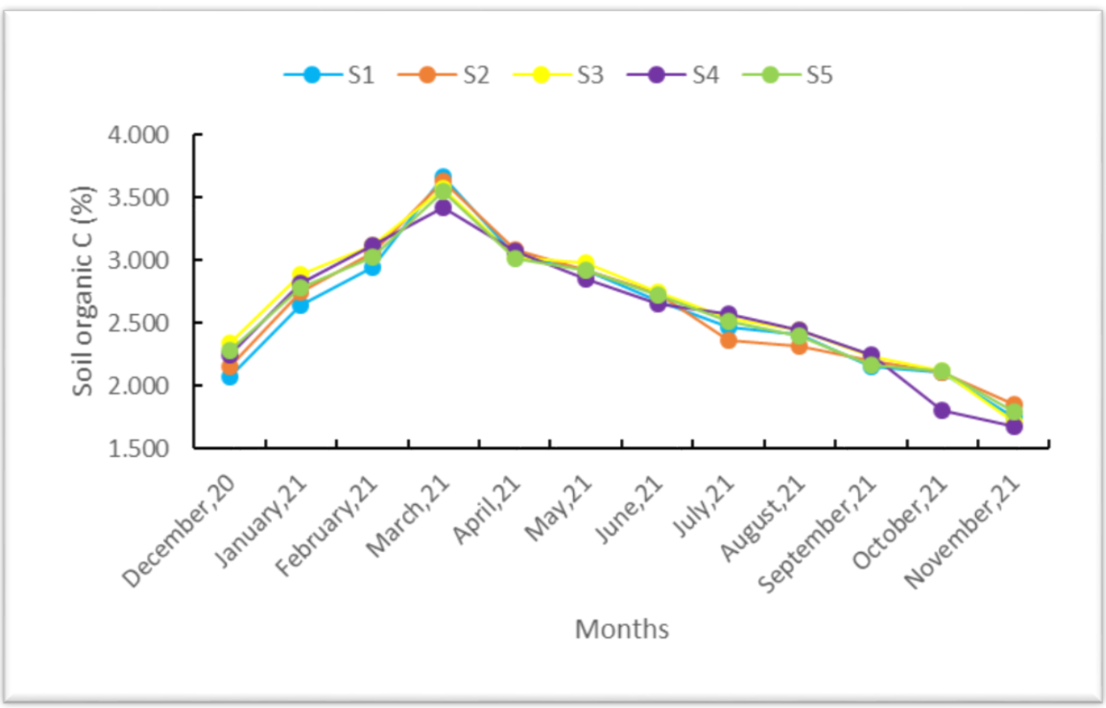


Figure 4.13 Monthly variation in organic carbon (%) of soil of Bansabati *beel*

Table 4.25 Two way ANOVA (with replication) to analyse month wise and station wise variation of soil pH of Bansabati *beel*

Source	Sum of Squares	DF	Mean Square	F	P
Months	18.222	11	1.657	496.950	<0.001
Stations	2.837	4	0.709	212.775	<0.001
Months*Stations	2.731	44	0.0621	18.620	<0.001
Residual	0.400	120	0.00333		

Table 4.26 Two way ANOVA (with replication) to analyse month wise and station wise variation of soil organic carbon of Bansabati *beel*

Source	Sum of Squares	DF	Mean Square	F	P
Months	42.850	11	3.895	641.985	<0.001
Stations	0.120	4	0.0300	4.939	0.001
Months*Stations	0.757	44	0.0172	2.834	<0.001
Residual	0.728	120	0.00607		

4.2.3 C/N Ratio

The two chemical components that are most crucial to organic matter are carbon and nitrogen, particularly in connection to or proportion to one another. The carbon-nitrogen ratio is the name given to this relationship. A key metric that links the composting processes to the relative quantities of crucial chemical components needed for the development and metabolic responses of the microbial population is the carbon to nitrogen (C/N) ratio. The main sources are carbohydrates and microbial biomass. They will provide the energy needed for microbial metabolic activity in addition to serving as sources of carbon for the microbial biomass. Proteins and amino acids, which are necessary for the development of the microbial biomass, must include nitrogen. In general, it is advised that the available carbon to nitrogen ratio be maintained at suitable levels in order to sustain an active microbial population in a composting process. Reduced ratios will cause nitrogenous compound losses, while increased ratios would slow the composting reactions (Inbar and Chet, 1991).

The C/N ratio obtained in the present study ranged from 7.50±0.02 to 17.49±0.20. The maximum ratio was observed in November 16.60±0.22, 17.49±0.20, 15.79±0.13, 15.51±0.24 and 16.82±0.07 at S1, S2, S3, S4 and S5 respectively. In April, C/N ratio showed a minimum value 7.57±0.06, 7.68±0.02, 7.54±0.06, 7.63±0.04 and 7.50±0.02 at S1, S2, S3, S4 and S5 respectively (Table 4.29 and Figure 4.15)

Two-way ANOVA indicated (Table 4.27) a significant difference ($P<0.05$) of C/N ratio of November month among other months. But there were no significant differences ($P>0.05$) among the sites. C/N ratio displayed (Table 4.30) a significant weak negative correlation ($P<0.05$) with soil pH in the *beel*.

According to Sugunan *et al*. (2000) soil quality varied widely between *beel*s, and between seasons and even different sampling sites within the same *beel*s. Generally, higher organic carbon contents (0.10-7.85%) were recorded in the weed choked closed *beel*s indicating high organic production in the water bodies. Closed but moderately weed infested *beel*s had comparatively lower organic carbon contents (0.12-5.99 %), while open (moderately weed infested) *beel*s recorded still lower values (0.10-2.31%). Closed *beel*s had comparatively higher total nitrogen (0.09-0.63 %) compared to open ones (0.04-0.16%) supporting the hypothesis that closed *beel*s are more productive but susceptible to eutrophication. This view is also corroborated by comparatively higher average C: N ratio (9.7-20.3) recorded in closed *beel* than those of open ones (8.00-13.83). Bala and Mukherjee (2011) reported that the value of total nitrogen were observed minimum in Mogra *beel* (0.29%) and minimum in Chakla *beel* (0.25%) and the value of C/N ratio were calculated maximum in Chand *beel* (46.46) and minimum in Arpara *beel* (8.50). But sediment C/N ratio should lie in the range of 10 to 17 and the results of the current study are in agreement with the optimum value.

The effective functioning of any aquatic ecosystem depends on the circulation of nutrients which takes place in most of the occasions at a faster rate especially in shallow tropical floodplain wetlands. Unlike small reservoirs, the *beel* ecosystem has its chief nutrient source from autochthonous input followed by allochthonous sources when during monsoon as run-off water enters into the *beel* inundating nearby crop fields if the *beel* is not well protected with embankments. In addition the open *beel*s are getting nutrients more during monsoon through their connections with the main river systems (Das, 2004).

Table 4.27 Two way ANOVA (with replication) to analyse month wise and station wise variation of C/N ratio of soil of Bansabati *beel*

Source	Sum of Squares	DF	Mean Square	F	P
Months	952.611	11	86.601	314.767	<0.001
Stations	1.965	4	0.491	1.786	0.136
Months*Stations	27.326	44	0.621	2.257	<0.001
Residual	33.015	120	0.275		

Table 4.28 Monthly variation in total nitrogen (%) of soil of Bansabati *beel*

Stations	December, 2020	January, 2021	February, 2021	March, 2021	April, 2021	May, 2021	June, 2021	July, 2021	August, 2021	September, 2021	October, 2021	November, 2021	Average
S1	0.212	0.222	0.277233	0.3382	0.401067	0.3449	0.287	0.251233	0.225833	0.197667	0.144533	**0.104767**	0.251
S2	0.213	0.223	0.2781	0.3367	0.400833	0.345833	0.287433	0.2538	0.228	0.1924	0.147167	0.105933	0.251
S3	0.214	0.226	0.275033	0.337633	0.400267	0.3468	0.289167	0.2521	0.224167	0.196033	0.146667	0.108467	0.251
S4	0.212	0.223	0.274833	0.3359	**0.401667**	0.3479	0.287333	0.2531	0.219167	0.188533	0.1454	0.1081	0.250
S5	0.207	0.221	0.273133	0.3341	0.401233	0.346467	0.2862	0.2528	0.220667	0.194767	0.1481	0.1064	0.249

Table 4.29 Monthly variation in C/N ratio of soil of Bansabati *beel*

Stations	December, 2020	January, 2021	February, 2021	March, 2021	April, 2021	May, 2021	June, 2021	July, 2021	August, 2021	September, 2021	October, 2021	November, 2021	Average
S1	9.73±0.15	11.89±0.16	10.59±0.04	10.84±0.06	7.57±0.06	8.47±0.04	9.30±0.07	9.79±0.08	10.67±0.05	10.86±0.13	14.52±0.06	16.60±0.22	10.907
S2	10.06±0.18	12.28±0.11	10.99±0.12	10.79±0.06	7.68±0.02	8.45±0.04	9.50±0.08	9.28±0.12	10.16±0.09	11.43±0.14	14.26±0.15	**17.49±0.20**	11.035
S3	10.85±0.09	12.75±0.14	11.34±0.09	10.58±0.07	7.54±0.06	8.57±0.06	9.49±0.10	10.03±0.08	10.89±0.08	11.39±0.10	14.45±0.13	15.79±0.13	11.145
S4	10.56±0.13	12.62±0.09	11.32±0.05	10.18±0.06	7.63±0.04	8.19±0.07	9.23±0.05	10.14±0.06	11.16±0.14	11.93±0.05	12.42±0.09	15.51±0.24	10.912
S5	10.97±0.12	12.57±0.11	11.06±0.09	10.60±0.09	**7.50±0.02**	8.40±0.04	9.50±0.06	9.94±0.05	10.87±0.04	11.09±0.04	14.31±0.13	16.82±0.07	11.140

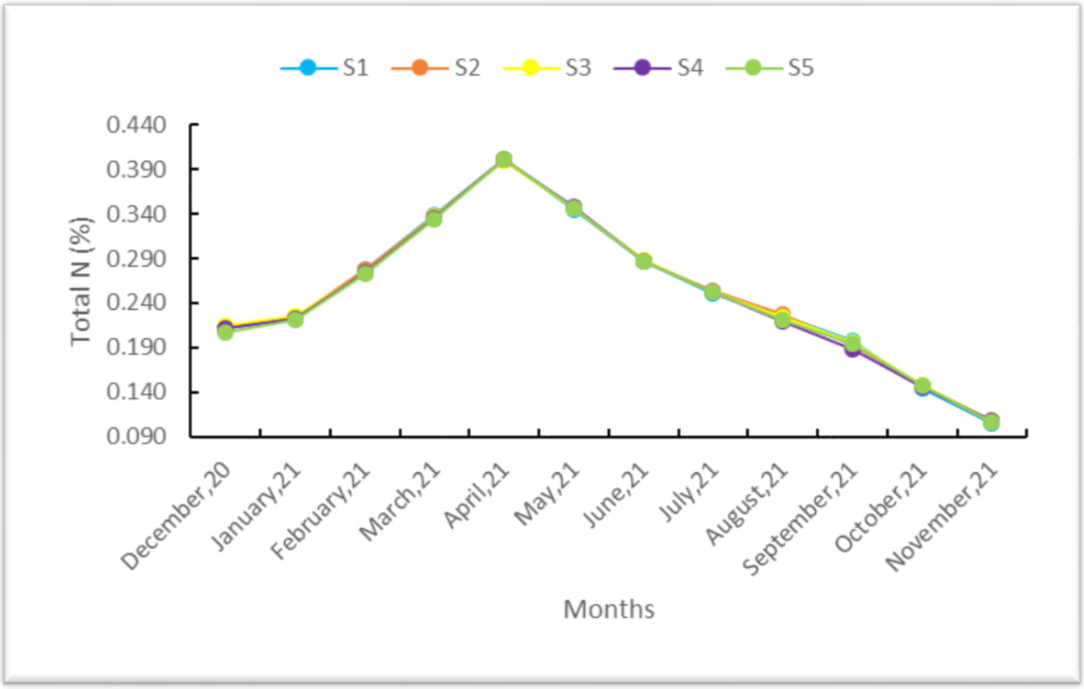


Figure 4.14 Monthly variation in total nitrogen (%) of soil of Bansabati *beel*

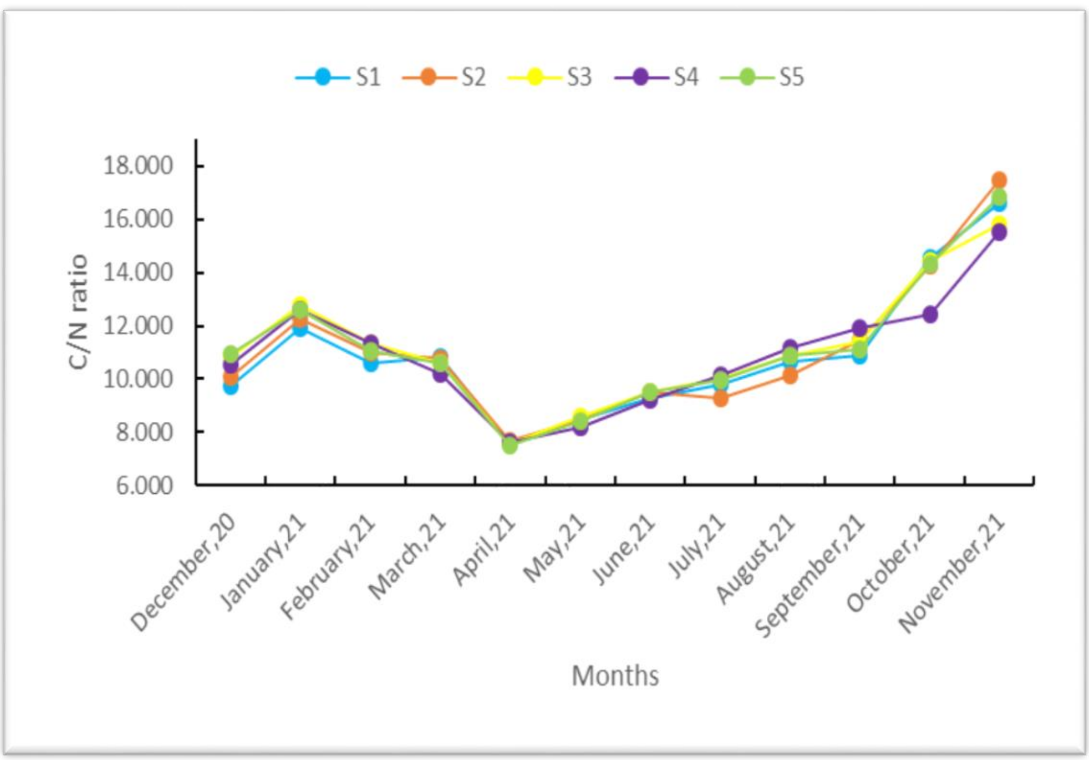


Figure 4.15 Monthly variation in C/N ratio of soil of Bansabati *beel*

Table 4.30 Pearson's Correlation matrix of the selected soil quality parameters of Bansabati *beel*

	Organic C	***CN Ratio***	***Total-N***	***pH***
Organic C	1			
CN Ratio	-0.56287*	1		
Total-N	0.852044*	-0.85778*	1	
pH	-0.00858	0.375019*	-0.17392*	1

'*' Correlation is significant at the 0.05 level (2- tailed)

4.3 Phytoplankton diversity at the Bansabati *beel*

The term plankton includes generally microscopic aquatic flora (phytoplankton) and fauna (zooplankton) having limited power of locomotion and drifted by water currents. Phytoplankters are primary producers which form the base of the autotrophic food chain. They are considered to be the best index of the biological productivity of aquatic habitat (Saksena, 1987), thus it is crucial for proper development of the fishes and other aquatic organisms (Shil *et al*., 2013). It also forms the basic link in all the dynamic features of lakes such as color, clarity, trophic state, and fish production depend to a large extent on the plankton. Thus it is considered as a good indicator of water quality and trophic conditions because of its rapid response to environmental changes and deterioration of water quality (Jindal *et al*., 2014).

The monthly abundance of phytoplankton in Bansabati *beel* during the study period ranged from 267 units/l to 864 units/l. The minimum density was observed in August 2021 and maximum in February 2021. During the study period higher phytoplankton density was observed during winter season, whereas lower density was observed during monsoon season. Monthly variation in phytoplankton abundance in Bansabati *beel* is presented in Figure 4.17 and Table 4.32.

A total of 18 phytoplankton species were identified at Bansabati *beel* (Plate 1) from all different five sites throughout the study period belonging to six groups of phytoplankton viz. Chlorophyceae, Bacillariophyceae, Cyanophyceae, Euglenophyceae and Zygnematophyceae. During the present observation among the phytoplankton population the group Chlorophyceae included five species namely *Tetraedron* sp, *Sphaerocystis* sp, *Microspora* sp, *Volvox* sp, and *Westella* sp; Bacillariophyceae included four species namely *Navicula* sp, *Gomphonema* sp, *Cyclotella* sp, *Epithemia* sp; *Cyanophyceae* represented two species namely *Calothrix* sp, *Chroococcus* sp; Euglenophyceae included one species namely *Trachelomonas* sp; Zygnematophyceae represented six species namely *Staurastrum* sp and *Cosmarium* sp, *Desmidium* sp, *Euastrum* sp, *Staurodesmus* sp, *Gonatozygon* sp.

In this present study, the maximum and minimum densities of the different species of Chlorophyceae group, like Tetraedron sp, Sphaerocystis sp, Microspora sp, Volvox sp, and Westella sp varied from 108 units/l to 42 units/l, 84 units/l to 22 units/l, 31 units/l to 0 units/l, 36 units/l to 0 units/l and 79 units/l to 37 units/l respectively.

Table 4.31 Overall group wise phytoplankton abundance recorded during study period in Bansabati *beel*

Group	Species	Site 1	Site 2	Site 3	Site 4	Site 5
Chlorophyceae	*Tetraedron* sp	+++	+++	++++	++++	+++
	Microspora sp	+	++	++	++	+
	Sphaerocystis sp	+++	++++	++++	++++	+++
	Volvox sp	+	+	++	++	+
	Westella sp	++	+++	++++	+++	++
Bacillariophyceae	*Navicula* sp	+	+	++	++	+
	Gomphonema sp	+	++	++	++	+
	Cyclotella sp	++	++	+++	++	+
	Epithemia sp	+	+	++	++	+
Cyanophyceae	*Calothrix* sp	+++	++++	++++	++++	+++
	Chroococcus sp	+	++	+++	++	+
	Desmidium sp	+	+	++	+	+
	Euastrum sp	+	+	++	++	+
	Staurodesmus sp	+	+	++	++	+
Zygnematophyceae	*Gonatozygon* sp	+	+	+	+	+
	Cosmarium sp	+	+	++	++	+
	Staurastrum sp	+	+	+	+	+
Euglenophyceae	*Trachelomonas* sp	+	++	++	+	+

++++= Most abundant; +++ = Common; ++= Moderate += Rare.

Table 4.32 Overall group wise phytoplankton abundance recorded during December, 2020 to November, 2021 in the Bansabati *beel*

Group	Species	Dec, 20 (u/l)	Jan, 21 (u/l)	Feb, 21 (u/l)	Mar, 21 (u/l)	Apr, 21 (u/l)	May , 21 (u/l)	Jun, 21 (u/l)	Jul, 21 (u/l)	Aug, 21 (u/l)	Sep, 21 (u/l)	Oct, 21 (u/l)	Nov, 21 (u/l)
Chlorophyceae	*Tetraedron* sp	91	96	108	88	72	81	70	48	42	57	84	95
	Microspora sp	19	26	28	22	29	31	30	0	0	0	17	21
	Sphaerocystis sp	67	70	84	70	45	55	36	33	22	69	70	70
	Volvox sp	32	34	36	0	0	0	0	0	0	26	28	35
	Westella sp	69	76	79	68	66	64	42	41	37	40	49	68
Bacillariophyceae	*Navicula* sp	26	31	34	22	20	24	25	16	15	19	20	24
	Gomphonema sp	21	23	27	17	16	18	13	08	06	15	16	19
	Cyclotella sp	48	43	43	49	36	40	33	12	12	36	44	43
	Epithemia sp	11	13	15	10	10	09	08	06	05	09	10	11
Cyanophyceae	*Calothrix* sp	205	221	231	164	165	169	188	77	81	82	126	149
	Chroococcus sp	36	42	56	34	41	43	45	24	17	12	28	30
	Desmidium sp	12	13	15	11	12	16	18	07	06	10	10	11
	Euastrum sp	14	14	15	12	13	18	19	05	03	11	14	15
	Staurodesmus sp	16	19	24	19	19	15	12	05	04	14	11	13
Zygnematophyceae	*Gonatozygon* sp	02	03	04	01	02	03	04	0	0	0	02	02
	Cosmarium sp	27	32	34	21	18	19	25	16	12	13	21	22
	Staurastrum sp	4	5	7	2	3	3	4	1	1	3	6	7
Euglenophyceae	*Trachelomonas* sp	18	21	24	11	13	15	17	7	4	14	16	17

Table 4.33 Overall species wise phytoplankton abundance recorded during December, 2020 to November, 2021 in the Bansabati *beel*

Months	Chlorophyceae		Cyanophyceae		Bacillariophyceae		Zygnematophyceae		Euglenophyceae		Total
	u/l	%	u/l	%	u/l	%	u/l	%	u/l	%	
Dec, 20	278	38.71866	241	33.56546	106	14.76323	75	4.317549	18	2.506964	718
Jan, 21	302	38.61893	263	33.63171	110	14.0665	86	4.731458	21	2.685422	782
Feb	335	38.77315	287	33.21759	119	13.77315	99	4.74537	24	2.777778	864
Mar	245	39.64401	198	32.03883	98	15.85761	66	3.721683	11	1.779935	618
Apr	212	36.55172	206	35.51724	82	14.13793	67	3.62069	13	2.241379	580
May	231	37.07865	212	34.02889	91	14.60674	74	3.5313	15	2.407705	623
Jun	178	30.22071	233	39.55857	79	13.41256	82	4.923599	17	2.886248	589
Jul	122	39.86928	101	33.00654	42	13.72549	34	5.555556	7	2.287582	306
Aug	101	37.82772	98	36.70412	38	14.23221	26	4.868914	4	1.498127	267
Sep	192	44.65116	94	21.86047	79	18.37209	51	3.72093	14	3.255814	430
Oct	248	43.35664	154	26.92308	90	15.73427	64	4.72028	16	2.797203	572
Nov	289	44.32515	179	27.45399	97	14.8773	70	4.447853	17	2.607362	652
total	**2733**		**2266**		**1031**		**794**	**11.34**	**177**		**7001**
%		**39.03**		**32.36**		**14.72**		**11.34**		**2.52**	100

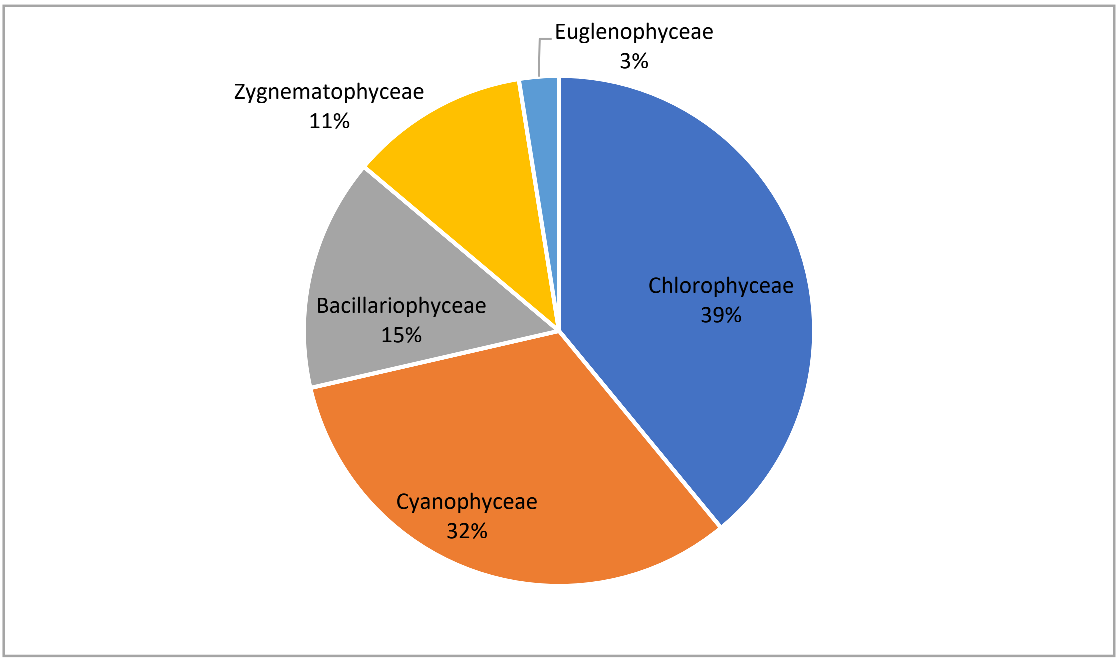


Fig 4.16 Overall phytoplankton groups in Bansabati *beel* from December, 2020 to November, 2021

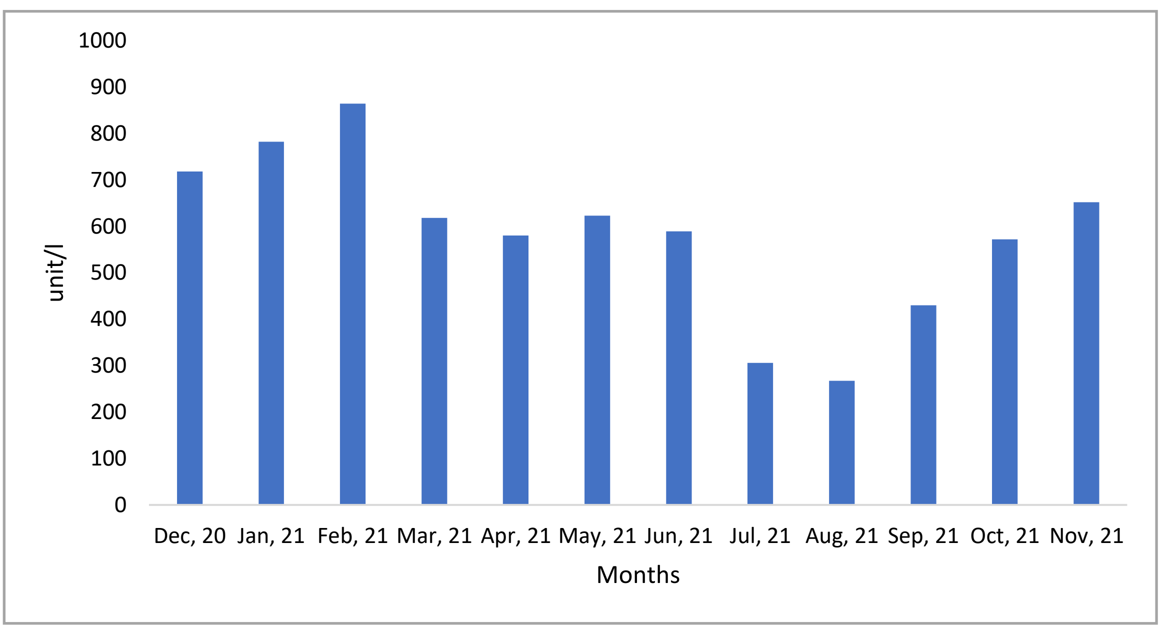


Fig 4.17 Monthly phytoplankton abundance in Bansabati *beel* from December, 2020 to November, 2021

Phytoplankton diversity of different wetlands of West Bengal have been studied by Rout *et al*. (2010) in Mathura *beel*, Nadia district and Ghosh *et al*. (2012) in Santragachi Lake and they have reported the phytoplankton diversity in the range of 22 to 29. They all reported Cyanophyceae as dominant family in their studies which is in concurrence with the present study. These findings are comparable with phytoplankton composition of the Bansabati *beel* recorded in the present study.

Among the Bacillariophyceae group, the maximum and minimum densities of *Navicula* sp, *Gomphonema* sp, *Cyclotella* sp, *Epithemia* sp; ranged from 34 units/l to 15 units/l, 27 units/l to 06 units/l, 49 units/l to 12 units/l, 15 units/l to 05 units/l, respectively. Among the Cyanophyceae group, the maximum and minimum densities of *Calothrix* sp, *Chroococcus* sp fluctuated 231 units/l to 77 units/l and 56 units/l to 12 units/l respectively. Among Euglenophyceae group, the maximum and minimum quantitative value of *Trachelomonas* sp varied from 24 units/l to 04 units/l. In Zygnematophyceae group, the maximum and minimum densities of *Staurastrum* sp, *Cosmarium* sp, *Desmidium* sp, *Euastrum* sp, *Staurodesmus* sp, *Gonatozygon* sp as recorded varied from 07 units/l to 01 unit/l, 34 units/l to 12 units/l, 18 units/l to 06 units/l, 19 units/l to 03 units/l, 24 units/l to 04 units/l and 04 units/l to 0 unit/l respectively.

According to Sugunan *et al*. (2000) availability of phytoplanktons in the West Bengal *beel*s ranged from 396-14987 u/l (mean value: 1188-11203 u/l). Rout *et al*. (2010) reported the phytoplanktons density ranged between 506 nos/l and 734 nos/l in Mathura *beel* spreading across the district of Nadia and North 24 parganas, West Bengal. Ziauddin *et al.* (2013) observed the phytoplankton has shown mean values of 1543.2 numbers/l and 1052 numbers/l for Saguna and Kole wetland in West Bengal. Keshri *et al*. (2013) reported the phytoplankton density was highest in post-monsoon (12633/l) followed by monsoon (10500/l) and pre-monsoon (7266/l) in Baishar *beel*, Nadia district, West Bengal. These findings are comparable with phytoplankton density of the Bansabati *beel*.

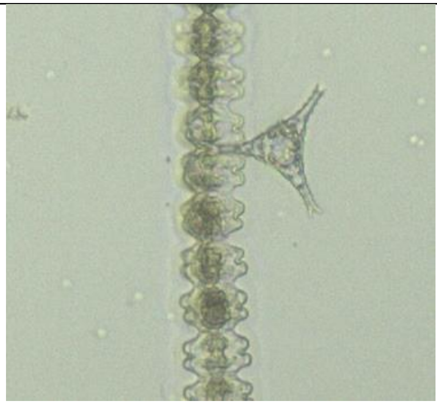
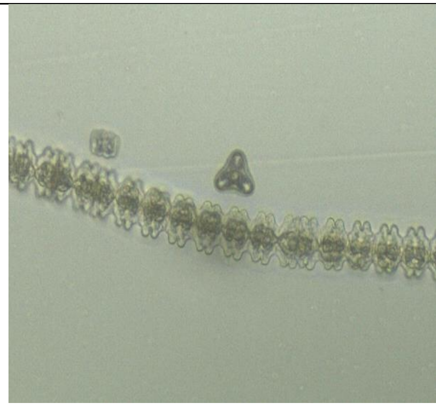
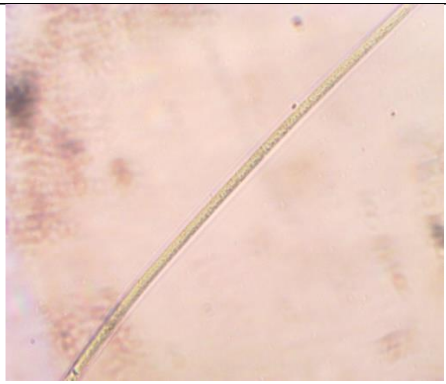
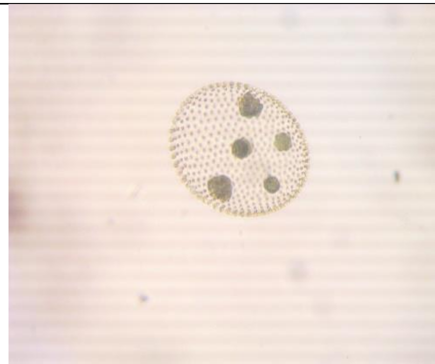
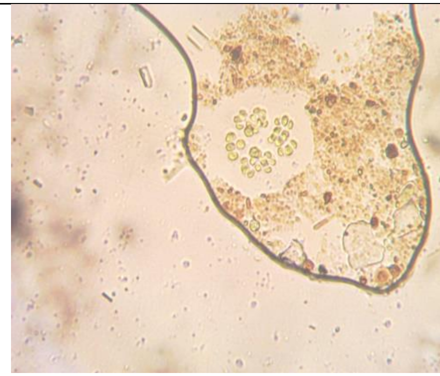
Overall phytoplankton abundance in terms of group-wise is presented in Table 4.32 and Fig 4.16. Among the various groups of phytoplankton, the population density of Chlorophyceae (39.03%) recorded the highest through the study period, which was followed by Cyanophyceae (32.36%), Bacillariophyceae (14.72%), Zygnematophyceae (11.34%), Euglenophyceae (2.52%). Singh *et al*. (2017) also observed that Chlorophyceae was the dominant phytoplankton group in the Bhara Haripota *beel* in Bhamanghata, South 24 Parganas district of West Bengal. Sugunan *et al*. (2000) reported that the group

Chlorophyceae dominated the plankton population in most weed choked (closed) *beel*s whereas Bacillariophyceae dominated in Bhomra (weed choked, closed) *beel*. In contrast, most moderately weed infested *beel*s (both closed and open types) showed the dominance of Cyanophyceae. Seventy four species of phytoplankton have been recorded in West Bengal *beel*s, which include twenty three diatoms, twenty green algae, seven blue green algae and four others. The blue-green algae dominated the summer peak population in Bhandardaha *beel*.

Among the planktons *Calothrix* sp, *Tetraedron* sp, *Westella* sp, *Sphaerocystis* sp, *Cyclotella* sp, *Chroococcus* sp, *Navicula* sp, *Cosmarium* sp were most abundance in the Bansabati *beel*. Overall density of phytoplankton was maximum in the month of February, 2021 reached a minimum in value at S1, S2, S3, S4 and S5 during August which then started increasing from September 2021. Overall density of phytoplankton is represented in Table 4.33.

Following the present study, during summer, an increase in temperature enhances evaporation followed by the rate of organic decomposition, increasing nutrient concentration resulting in the presence of abundant food for phytoplankton reflecting their high density (Santhanam and Perumal, 2003). During the monsoon season, due to runoff from the nearby field, which transports soil and other plant and animal debris into the lake could have changed the physicochemical properties of water leading to physiological stress on the plankton community. It was found that the light is an important factor for the growth of phytoplankton but during this period, due to the presence of high dissolved solids in the Lake water reflecting on the decrease in transparency leading to low penetration of sunlight into the Lake. It might have caused mortality and thus reduced the density as also opined by earlier researcher (Chalinda *et al*., 2004; Hassan *et al*., 2011 and Singh *et al*., 2017). But in the post-monsoon season, due to settlement of more nutrients by an increased fertility condition of the *beel*, might have resulted in higher density in the phytoplankton community. A similar observation was reported by Ghosh and Biswas (2015). Likewise, during the winter season, it was recorded higher active absorption of these nutrients resulting drop in nitrate and phosphate level may be due to consumption by algae. This is in agreement with the findings of Temponeras *et al*. (2000) and Javeed *et al*. (2019). During these winter months, dissolved oxygen produced by phytoplankton biomass, was higher due to their photosynthetic activity. Therefore, dissolved oxygen was found higher, where phytoplankton count was highest in density. A similar variation was reported by Kangabam *et al*. (2017) and Sharma and Tiwari (2018).

Plate 4.1 Dominated phytoplankton species of the Bansabati *beel*

Chlorophyceae		
		
Tetraedron sp	*Tetraedron* sp	*Sphaerocystis* sp
		
Microspora sp	*Volvox* sp	*Westella* sp

<table>
<tr><th colspan="6">Cyanophyceae</th></tr>
<tr><td colspan="3"></td><td colspan="3"></td></tr>
<tr><td colspan="3">Calothrix sp</td><td colspan="3">Chroococcus sp</td></tr>
<tr><th colspan="6">Bacillariophyceae</th></tr>
<tr><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td colspan="2">Naviculla sp</td><td colspan="2">Gomphonema sp</td><td colspan="2">Cyclotella sp</td></tr>
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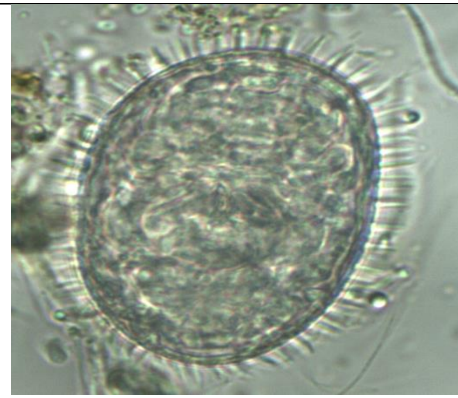
<tr><td colspan="3"></td><td colspan="3"></td></tr>
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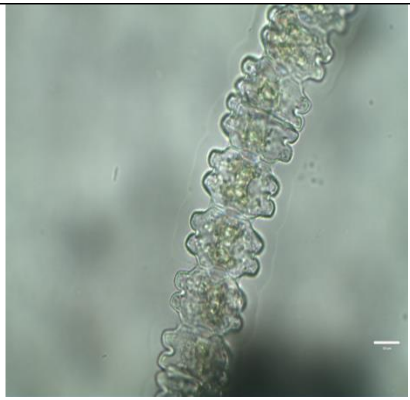
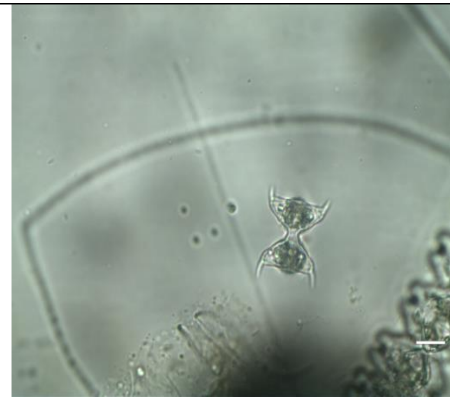
<tr><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
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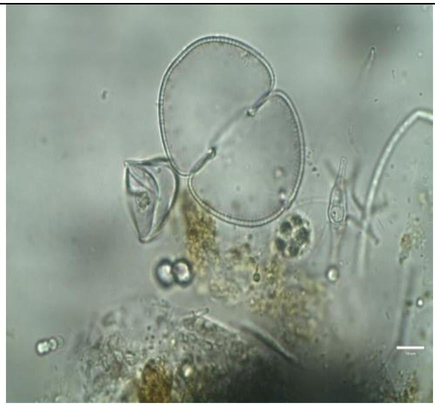
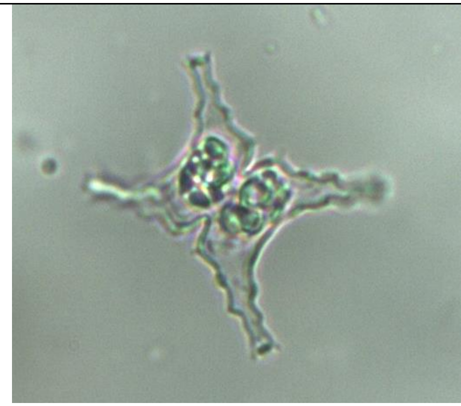
<tr><td></td><td></td><td></td></tr>
<tr><td>Cosmarium sp</td><td>Cosmarium sp</td><td>Staurastrum sp</td></tr>
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4.6 Macrophytes diversity at the Bansabati *beel*

Aquatic macrophytes diversity and its role in understanding the wetland ecosystem dynamics have tremendous significance. Macrophytes can be used as tool in the determination of pollution and nutrient level, water quality and lake condition, trophic status (Arya *et al*., 2018).

Aquatic macrophytes have profound influence on the ecology and fisheries of the floodplain wetlands. As already discussed, water of weed choked *beel*s tend to have lower pH, turbidity and nutrient concentrations as well as high diurnal variation of dissolved oxygen and carbon dioxide. The macrophytes compete for plant nutrients and space with phytoplankton. As a result, low phytoplankton biomass is observed on weed infested *beel*s. In general, macrophytes are not consumed by fishes with the exception of some species like grass carp which feeds on a few soft submerged plants like *Hydrilla* sp, *Ceratophyllum* sp, etc. Thus, most of the solar energy fixed by the macrophytes are converted to fish-flesh, only through the weed-detritus food chain. However, the macrophytes harbour; aquatic insects and molluscs which form food for some fishes.

Aquatic plants contribute considerably to the bottom detritus, thereby encouraging fast colonisation of benthic organisms when present in reasonable quantities. Heavy weed infestation has many harmful effects on the ecology and fisheries of the *beel*s since it renders the operation of fishing gear difficult, predominance of air breathing and carnivorous fishes instead of planktivorous ones thereby reducing the efficiency of conversion of solar energy into fish biomass. Because of their harmful effects, the macrophytes are also termed as aquatic weeds, especially when they grow in excessive quantities. However, the growth of certain amount of aquatic macrophytes along the margins can be considered desirable as it can reduce the wave action on the banks and prevent occurrence of algal bloom.

During the study period, a total of 08 species of macrophytes were recorded (Table 4.34; Plate 4.2). The floristic composition shows that the vegetation of macrophytes in Bansabati *beel* includes 4 species (50%) were submerged macrophytes, 4 species (50%) were free floating. The dominant family was Pontedericacea. A detailed description of macrophytes in the study area is presented in Table 4.34.

However, Patra *et al*. (2017) identified 29 species of aquatic macrophytes from Santragachi Jheel, Howrah district of West Bengal which was higher in number than the present study. Das *et al*. (2009) reported Altogether 13 genera of aquatic macrophytes belonging to 10 families, and 24 plant species (bank flora) belonging to 16 families in the Hansadanga *beel*, Nowapara *beel* and Kaji *beel* Krishnagar city, West Bengal, India. Some authors also observed seasonal variations in abundance of macrophytes. Ghosh and Biswas (2015) examined among emergent, *Cynodon* sp was the most dominant during pre-monsoon and post-monsoon and *Ipomoea* sp during monsoon. Among the free-floating genus, *Eichhornia* sp was highly dominant throughout the year while *Lemna* sp topped the group during pre-monsoon. Among the submerged genus, *Hydrilla* sp was observed to be the most dominant genus throughout the year. Among rooted floating-leaved *Nymphaea* sp was highly dominant during monsoon and post-monsoon and *Brasenia* sp during pre-monsoon. Sugunan *et al*. (2000) reported the *beel*s in West Bengal under study were infested by aquatic macrophytes with varying extent of infestation and all the open *beel*s (e.g. Palda, Kol, etc.) were only moderately weed infested (average < 50% of water area covered by macrophytes).

Table 4.34 Dominated aquatic macrophytes of Bansabati *beel* from December, 2020 to November, 2021

Category	Family	Number	Species	Common name	Local name
Floating	Pontederiaceae	1	*Eichhornia* sp	Water Hyacinth	Kochuripana
	Nymphaeaceae		*Nymphaea* sp	Water Lily	Shapla
	Lythraceae	3	*Trapa* sp	Water Chestnut	Paniphal
	Salviniaceae	4	*Salvinia* sp	African Payal	Salvinia
Submerged	Potamogetonaceae	5	*Potamogeton* sp	Long leaf pond weed	Potas
	Characeae	6	*Chara* sp	Musk grass	Kara
	Hydrocharitaceae	7	*Hydrilla* sp	Hydrilla	Jalkhangi
	Ceratophyllaceae	8	*Ceratophyllum* sp	Coontail	Jhanji

Plate 4.2 Dominated macrophytes of Bansabati *beel* during the study period from December, 2020 to November, 2021

Floating			
			
Salvinia sp	*Nymphaea* sp	*Trapa* sp	*Eichhornia* sp
Submerged			
			
Potamogeton sp	*Chara* sp	*Hydrilla* sp	*Ceratophyllum* sp

4.7 Ichthyofaunal diversity of Bansabati *beel*

Ichthyofaunal composition is presented in Table 4.35, along with details on trophic level, feeding habit, fisheries relevance and IUCN Red List status of each species. A total of 42 species of fish belonging to 9 orders, 21 families and 32 genera were documented during the study period. With eleven species, the Cyprinidae family was the dominant, followed by Channidae (four species) and Mastacembelidae (three species) (Table 4.36). Xenocyprididae, Danionidae, Cichlidae, Bagridae, Ambassidae and Siluridae had two species each. There were some families which were the rarest, *viz*., Cobitidae, Nandidae, Gobiidae, Osphronemidae, Anabantidae, Clariidae, Heteropneustidae, Ailiidae, Synbranchidae, Belonidae, Notopteridae and Tetraodontidae, which were collectively grouped as miscellaneous. Among the 42 species recorded in the present study, 24 (57.14%) were abundantly available, 4 (9.52%) were commonly available, 9 (21.42%) were moderately available and 5 (11.90%) were rarely available. *Puntius sophore, Pethia conchonius, Amblypharyngodon mola* and *Mystus vittatus* were the most abundant; while *Labeo bata, Cyprinus carpio, Hypophthalmichthys molitrix, Oreochromis niloticus* and *Leiodon cutcutia* were the rarest.

Wetlands are home to a wide variety of species because of the crucial role that microorganisms play in enhancing nutrient bioavailability and hence increasing ecosystem productivity. Wetlands are therefore seen as being the habitats most suitable for ecological growth (Mohan *et al.,* 2020). Several authors have documented and described the freshwater ichthyofaunal diversity of West Bengal and their threatened status (Barman, 2007; Mogalekar *et al*., 2017). They reported between 239 and 267 different species, including both native and exotic species as well as primary and secondary freshwater forms. There is a wealth of literature on fish and fisheries in West Bengal, notably from *beels* (Sugunan *et al.,* 2000; Mondal and Kaviraj, 2009; Mistry, 2016; Ghosh and Biswas, 2017; Pal *et al.* 2018; Mohan *et al.,* 2020; Sarkar *et al.,* 2020). Number of fish species recorded by them varied between 19 in Chaltia *beel* (Sarkar *et al*., 2020) and 54 in Patan wetland (Dey, 2017) with Cyprinidae as the dominant family, which is comparable with the present study. Sugunan *et al.* (2000) opined that open *beel*s, although less productive, harbour riverine species in addition to resident species. They reported a total of 55 fish species in open *beels* and 42 fish species in closed *beels* of West Bengal. The moderate to rich fish diversity (42 species) of the Bansabati *beel* may be due to open wetland, which offers greater habitat for native fish species and enhanced access to the river (Sarkar *et al.,* 2020). The fish species found in the Bansabati *beel* and those reported in earlier studies are consistent with the species found in the Gangetic delta (Das *et al.,* 2020; Sarkar *et al.*, 2021).

In the present study, the percentage composition of carnivores was higher (48%) followed by omnivores (36%) and herbivores (17%) (Figure 4.19). Likewise, Pal *et al.* (2018) in Panishala *beel* and Mohan *et al.* (2020) in East Kolkata Wetlands also reported a higher percentage of carnivores (53-56.41%). The trophic level of fish varied between 2.0 and 4.5 with *Channa marulius* emerging as the top-most predator in the *beel*. The other top carnivore fish included *Xenentodon cancila* (3.9), *Nandus nandus* (3.9), *Ophichthys cuchia* (3.8), *Ompok pabda* (3.8), *Channa orientalis* (3.8) and *Channa punctata* (3.8) (Froese and Pauly, 2020). Omnivores tend to be particularly tolerant to deteriorating surroundings due to their ability to ingest food from a variety of sources in a changing ecology (Wichert and Rapport, 1998). Therefore, when a system is least disturbed, the types of species that dominate tend to be benthic feeders and carnivores rather than omnivores in comparison to a degraded site (Karr *et al*., 1986; Hughes and Oberdorff, 1998). Thus, it appears that the Bansabati *beel* was least disturbed, as evidenced by the dominance of carnivores there.

It was found that the Bansabati *beel* harbours about two-thirds of fish species important to fisheries and with potential market value for both food and ornamental uses. While studyin g the ichthyofaunal diversity of the Panishala *beel* in Cooch Behar, Pal*et al.* (2018) observed that 10 species (26%) were food fish, whereas 14 species (36%) were counted as food fish and ornamental side by side. The IUCN Red List (IUCN, 2022) status of fish species of Bansabati *beel* (Figure 4.20) inferred that one species (2.38%) named *Clarias magur* was categorized as 'Endangered' (EN), three species, viz., *Wallago attu, Oreochromis mossambicus* and *C. carpio* were 'Vulnerable' (VU) comprising 7.14% of the listed fish. Three species (7.14%) were 'Near threatened' (NT), namely *O. pabda, H. molitrix* and *Ailia coila*. Thirty-five of the listed fish comprising 83.33% were 'Least Concern' (LC). Anthropogenic stress is continuously affecting the fish fauna of wetlands, which is causing a persistent fall in their population (Carpenter *et al.*, 2011; Sarkar and Borah, 2017; Sarkar *et al.,* 2020). A decline in as many as 19 fish species was noticed in Chaltia *beel* in 2020 compared to 15 years back in the same *beel* (Sarkar *et al.,* 2020). Local fishers of the Bansabati *beel* claim that numerous fish species and their abundances have decreased over the past 2 – 3 decades; however there is no prior literature to support their claims. According to them, *Sperata aor* and *Systomus sarana* were formerly abundant in this *beel* and lost their numbers over years. *Tenualosa ilisha* was also reportedly abundant in this *beel*, which was made feasible by its connection to the Ganges before the construction of the Farakka barrage and feeder canal.

Table 4.35 Ichthyofaunal diversity of Bansabati *beel* recorded during the study period

Order	Family	Scientific name	English common name	Local name	Feeding habitat	Trophic level	Fishery importance	IUCN Red List status	Frequency
Cypriniformes	Cyprinidae	*Labeo bata* (Hamilton,1822)	Bata	Bata	H	2.0±0.00	FF, CI	LC	+
		Labeo rohita (Hamilton,1822)	Roho labeo	Rohu/rui	H	2.2±0.12	FF, CI	LC	++++
		Labeo catla (Hamilton,1822)	Catla	Catla	H	2.8±0.22	FF, CI	LC	++++
		Cirrhinus mrigala (Hamilton,1822)	Mrigal	Mrigal	O	2.2±0.20	FF, CI	LC	++
		Labeo calbasu (Hamilton,1822)	Orange fin labeo	Kalbose	O	2.0±0.00	FF, OF, CI	LC	+++
		Pethia ticto (Hamilton,1822)	Ticto barb	Chena puthi	O	2.2±0.00	FF, OF, CI	LC	++
		Labeo gonius (Hamilton,1822)	Kuria labeo	Kursa	H	2.0±0.00	FF, CI	LC	++++
		Cyprinus carpio Linnaeus, 1758	Common carp	American rui	O	3.1±0.00	FF, CI, Ex	VU	+
		Systomus sarana (Hamilton, 1822)	Olive barb	Sarpunti	O	2.9±0.20	FF, OF, CI	LC	++
		Puntius sophore (Hamilton, 1822)	Pool barb	Jatpunti	O	2.6±0.10	FF, OF	LC	++++
		Pethia conchonius (Hamilton, 1822)	Rosy barb	Kunchopunti	O	2.9±0.33	FF, OF	LC	++++
	Xenocyprididae	*Hypophthalmichthys molitrix* (Valenciennes,1844)	Silver carp	Silver Carp	H	2.0±0.00	FF. CI, Ex	NT	+
		Ctenopharyngodon idella (Valenciennes, 1844)	Grass carp	Grass carp	H	2.0±0.00	FF,CI, Ex	LC	++
	Danionidae	*Rasbora daniconius* (Hamilton, 1822)	Flying barb	Danrica	O	2.4±0.10	FF, OF	LC	++++
		Amblypharyngodon mola (Hamilton, 1822)	Mola carplet	Mourala	H	3.2±0.40	FF, CI	LC	++++
	Cobitidae	*Lepidocephalichthys guntea* (Hamilton, 1822)	Guntea loach	Guntea	O	2.7±0.20	FF, OF	LC	++++
Cichliformes	Cichlidae	*Oreochromis mossambicus* (Peters, 1852)	Mozambique tilapia	Tilapia	O	2.2±0.00	FF, CI	VU	++
		Oreochromis niloticus (Linnaeus, 1758)	Nile tilapia	Nilotica	O	2.0±0.00	FF, CI	LC	+
	Ambassidae	*Chanda nama* Hamilton, 1822	Elongate glass perchlet	Kath chanda	C	3.6±0.54	FF, OF, CI	LC	++++
		Parambassis ranga (Hamilton, 1822)	Indian glassy fish	Rangachanda	C	3.5±0.32	FF, OF, CI	LC	++++
Siluriformes	Heteropneustidae	*Heteropneustes fossilis* (Bloch, 1794)	Stinging catfish	Singhi	C	3.6 ±0.30	FF, OF, CI	LC	++++
	Clariidae	*Clarias magur* (Hamilton, 1822)	Philippine catfish	Magur	C	3.4±0.50	FF, OF, CI	EN	++++
	Bagridae	*Mystus vittatus* (Bloch, 1794)	Striped dwarf catfish	Tengra	C	3.1±0.10	FF, OF, CI	LC	++++
		Sperata aor (Hamilton, 1822)	Long-whiskered catfish	Aormach	C	3.6±0.53	FF, OF, CI	LC	++
	Siluridae	*Wallago attu* (Bloch & Schneider, 1801)	Wallago	Boal	C	3.7±0.56	FF, OF, CI	VU	++++
		Ompok pabda (Hamilton, 1822)	Pabdah catfish	Pabda	C	3.8±0.60	FF, OF CI	NT	+++

Order	Family	Scientific name	English common name	Local name	Feeding habitat	Trophic level	Fishery importance	IUCN Red List status	Frequency
	Ailiidae	*Ailia coila* (Hamilton, 1822)	Gangetic ailia	Banspata	O	3.6±0.60	FF, CI	NT	++++
Synbranchiformes	Mastacembelidae	*Mastacembelus armatus* (Lacepede, 1800)	Zig-zag eel	Ban	C	2.8±0.27	FF, OF, CI	LC	++
		Macrognathus aral (Bloch & Sceider, 1801)	One-stripe spiny eel	Gochi	C	3.1±0.33	FF, OF, CI	LC	++++
		Macrognathus pancalus Hamilton, 1822	Barred spiny eel	Pankal	O	3.5±0.51	FF, OF	LC	++++
	Synbranchidae	*Ophichthys cuchia* (Hamilton, 1822)	Cuchia	Kuchha	C	3.8±0.64	FF, OF	LC	++
Osteoglossiformes	Notopteridae	*Notopterus notopterus* (Pallas, 1769)	Bronze featherback	Folui	C	3.5±0.00	FF, OF, CI	LC	++++
Beloniformes	Belonidae	*Xenentodon cancila* (Hamilton, 1822)	Freshwater garfish	Bok Mach	C	3.9±0.62	FF	LC	+++
Tetraodontiformes	Tetraodontidae	*Leiodon cutcutia* (Hamilton, 1822)	Ocellated puffer fish	Cutcutia/ tapa	O	3.3±0.20	OF	LC	+
Gobiiformes	Gobiidae	*Glossogobius giuris* (Hamilton, 1822)	Tank goby	Belay	C	3.7±0.20	FF, OF, CI	LC	+++
Anabantiformes	Channidae	*Channa orientalis* Bloch & Schneider, 1801	Walking snakehead	Cheng	C	3.8±0.59	FF, EX	LC	++
		Channa punctata (Bloch, 1793)	Spotted snakehead	Lata	C	3.8±0.70	FF, CI	LC	++++
		Channa striata (Bloch, 1793)	Striped snakehead	Shol	C	3.4±0.45	FF, OF	LC	++++
		Channa marulius (Hamilton, 1822)	Great snakehead	Gajar/ Shal	C	4.5±0.80	FF, OF, CI	LC	++++
	Anabantidae	*Anabas testudineus* (Bloch, 1792)	Climbing perch	koi	C	3.0±0.40	FF, OF	LC	++++
	Nandidae	*Nandus nandus* (Hamilton, 1822)	Gangetic leaf fish	Veda	C	3.9±0.63	FF, OF, CI	LC	++++
	Osphronemidae	*Trichogaster fasciata* Bloch & Schneider, 1801	Banded gourami	Kholisa	O	3.1±0.30	FF, OF	LC	++++

FF - Food fish; OF - Ornamental fish; CI - Commercially important; Ex - Exotic; H - Herbivore; O - Omnivore; C - Carnivore; IUCN = International Union for Conservation of Nature and Natural Resources; EN = Endangered; VU = Vulnerable; NT = Near Threatened; LC = Least Concern; ++++= Most abundant; +++ = Common; ++= Moderate += Rare.

Table 4.36 Diversity of fishes from Bansabati *beel* during the study period from December, 2020 to November, 2021

Order	Families	No of Genera	No of Species
Cypriniformes	Cyprinidae	06	11
	Xenocyprididae	02	02
	Danionidae	02	02
	Cobitidae	01	01
Cichliformes	Cichlidae	01	02
	Ambassidae	02	02
Siluriformes	Heteropneustidae	01	01
	Clariidae	01	01
	Bagridae	02	02
	Siluridae	02	02
	Ailiidae	01	01
Synbranchiformes	Mastacembelidae	02	03
	Synbranchidae	01	01
Osteoglossiformes	Notopteridae	01	01
Beloniformes	Belonidae	01	01
Tetraodontiformes	Tetraodontidae	01	01
Gobiiformes	Gobiidae	01	01
Anabantiformes	Channidae	01	04
	Anabantidae	01	01
	Nandidae	01	01
	Osphronemidae	01	01
Total = 9	Total = 21	Total = 32	Total = 42

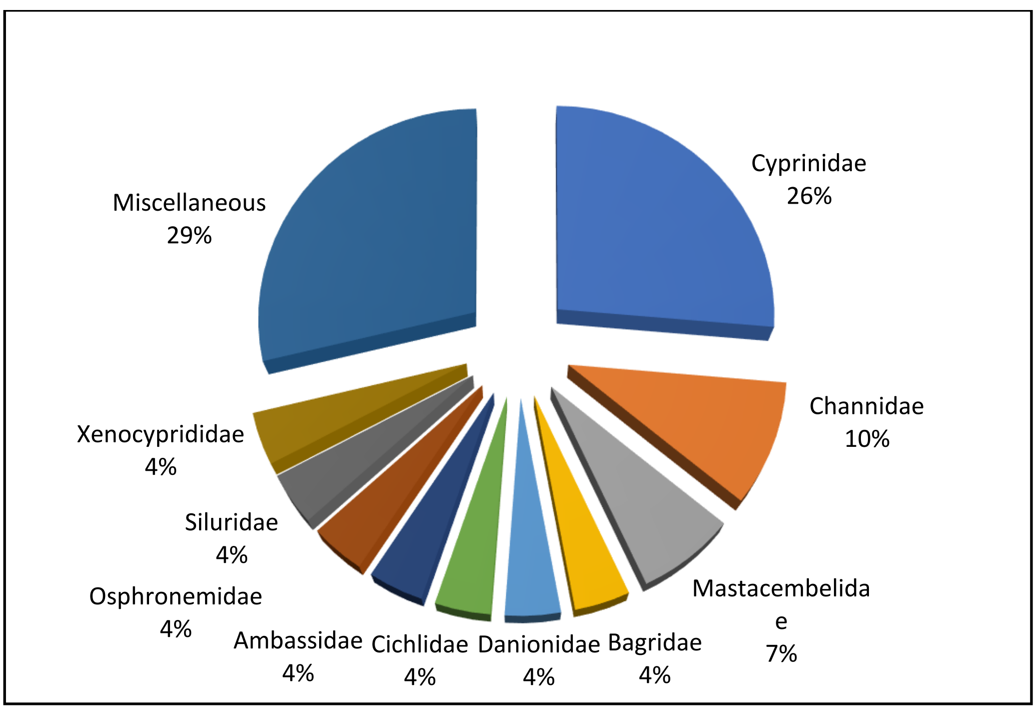


Figure 4.18 Family-wise distribution of fish species in Bansabati *beel*

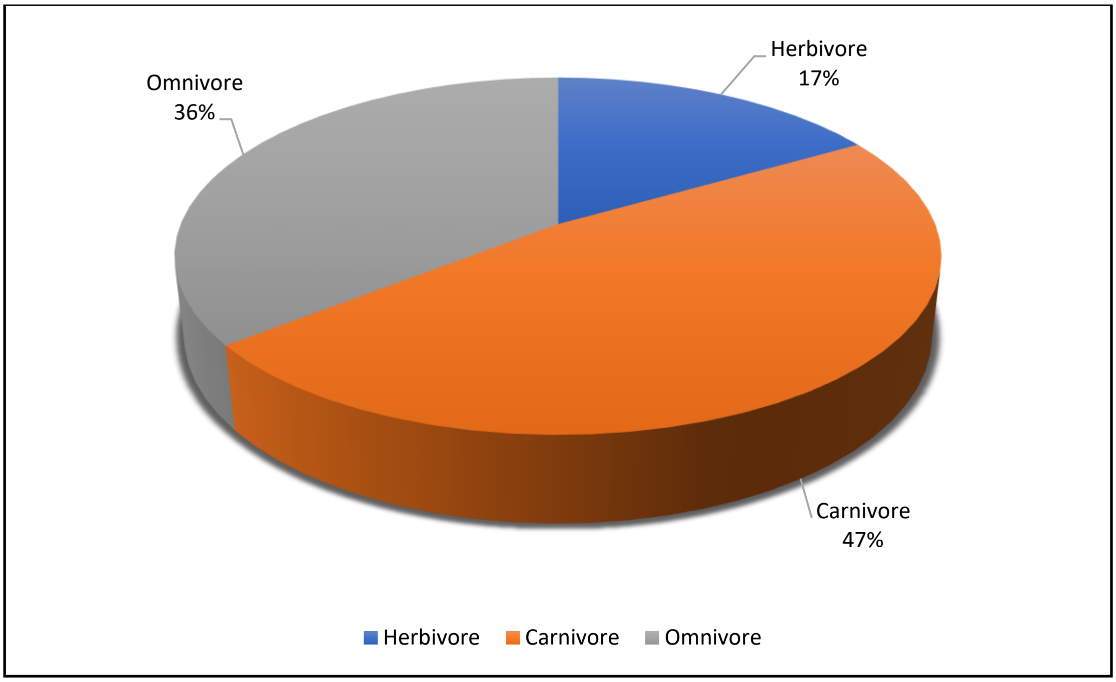


Figure 4.19 Composition of fish species with different feeding habits in Bansabati beel

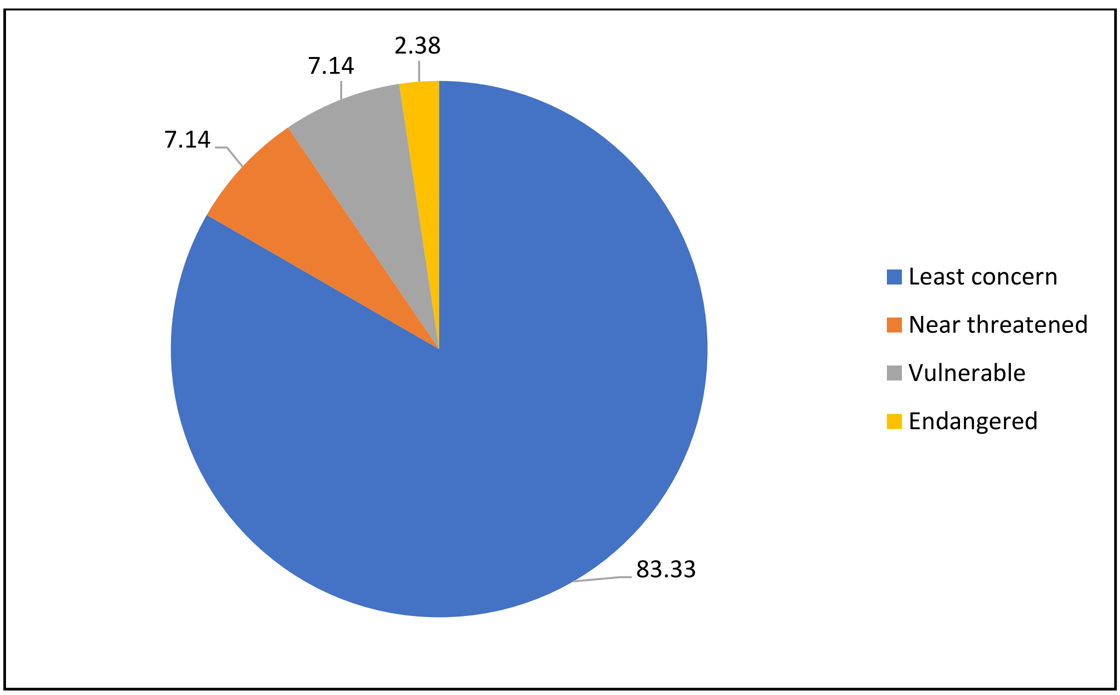


Figure 4.20 The IUCN Red list status of the fish of Bansabati *beel*

Plate 4.3 Ichthyofaunal diversity of Bansabati *beel* during the study period

Labeo rohita

Labeo catla

Cirrhinus mrigala

Labeo gonius

Labeo calbasu

Labeo bata

Systomus sarana

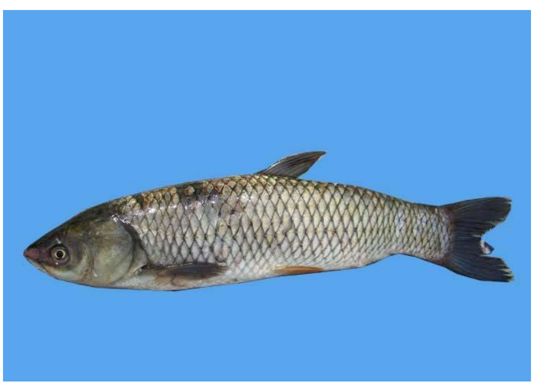
Pethia conchonius

Puntius sophore

Pethia ticto

Cyprinus carpio

Hypophthalmichthys molitrix



Ctenopharyngodon idella

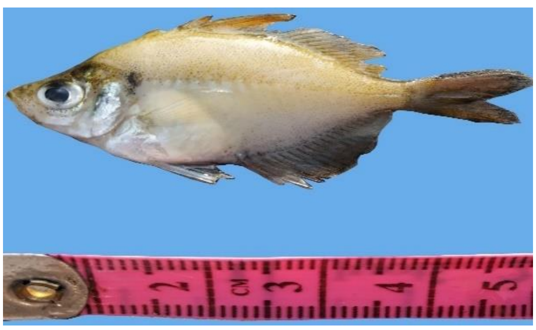
Rasbora daniconius

Amblypharyngodon mola

Lepidocephalichthys guntea

Oreochromis mossambicus

Oreochromis niloticus



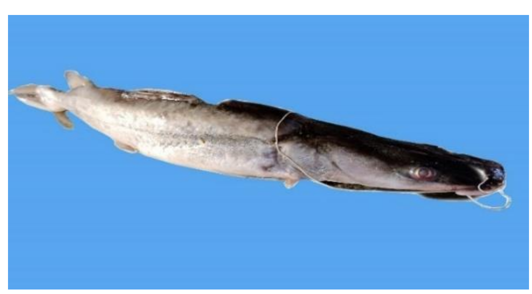
Chanda nama

Parambassis ranga

Heteropneustes fossilis

Clarias magur

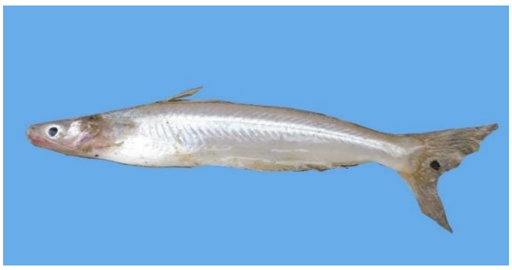
Mystus vittatus



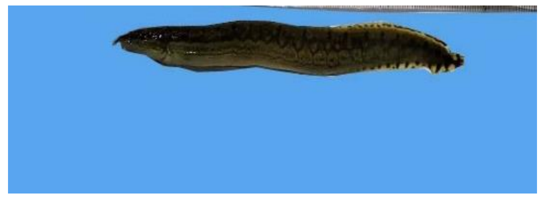
Sperata aor

Wallago attu

Ompok pabda



Ailia coila



Mastacembelus armatus

Macrognathus aral

Macrognathus pancalus

Ophichthys cuchia

Notopterus notopterus

Xenentodon cancila

Leiodon cutcutia

Glossogobius giuris

Channa orientalis

Channa punctata

Channa striata

Channa marulius

Anabas testudineus

Nandus nandus

Trichogaster fasciata

4.7.1 Species diversity indices

In the present study, monsoon witnessed a minimum number of 31 fish species whereas a maximum of 42 species were found during winter and post-monsoon periods. The corresponding mean values of Margalef's richness were 4.334 and 5.423 in monsoon and post-monsoon (Table 2). Margalef's richness varied significantly ($P<0.05$) depending on the season: pre-monsoon and post-monsoon, monsoon and post-monsoon, winter and monsoon, and winter and monsoon. Various authors reported the index value in the range of 0.68 – 14.12 in freshwater *beels* (Rahman *et al.,* 2019; Sarkar and Saha, 2021; Kunda *et al.,* 2022) with highest values in post-monsoon in their studies. Margalef's richness, used to evaluate community structure, generally shows deviation depending on the species number (Vyas *et al.,* 2012). Low fish diversity in open *beel*s in monsoon compared to post-monsoon may be due to the movement of certain fish species to the adjoining low-lying areas for breeding and recruitment as also observed by Mondal *et al*. (2010) and Sarkar and Saha (2021). Later, they return to the *beel* once the flood is over, thereby increasing species numbers in post-monsoon and winter periods. Macrophtye influx in open *beel* during monsoon might also hamper plankton growth and fish diversity (Sugunan *et al.,* 2000).

Simpson's diversity index is used to calculate diversity difference in a community. Value generally ranges from 0 (low or no diversity) to 1 (high diversity) (Ali *et al.,* 2020). Therefore, the current value indicated that Bansabati *beel* has moderate to rich fish diversity. The highest Simpson diversity index value (0.918) was observed during post-monsoon and the least during pre-monsoon (0.890). Kunda *et al.* (2022) also observed highest value in post-monsoon. Different authors have reported the value from 0.610 to 0.944 in *beels* of West Bengal and Bangladesh (Ghosh and Biswas, 2017; Rahman *et al.,* 2019; Triparna *et al.,* 2021; Sarkar and Saha, 2021). There existed a significant difference ($P<0.05$) in the Simpson index between the pre-monsoon and post-monsoon seasons. The higher value of the Simpson index (0.918) in post-monsoon could be attributed to the favourable environmental conditions and reproduction of fishes during monsoon season leading to a greater assemblage (Kunda *et al.,* 2022).

Shannon-Wiener diversity index (H') is used for calculating entropy and estimating species diversity. i.e. richness and evenness. The value usually ranges between 1.5 and 3.5 for ecological and a value above 3.0 signifies higher diversity, and a generally stable and balanced habitat structure (Magurran, 2005). In the present study, pre-monsoon recorded lowest of H’ (2.786) and post-monsoon witnessed the highest value (3.018) (Table 2) indicating the Bansabati *beel* has moderate to high diversity with healthy environment. The Shannon-Wiener diversity index (H') showed a significant difference ($P<0.05$) between the winter and pre-monsoon, winter and monsoon, pre-monsoon and post-monsoon, and monsoon and post-monsoon seasons. Similarly, highest value during post-monsoon was reported by Mondal *et al.* (2010), Sarkar *et al.* (2020), Sarkar and Saha (2021), Triparna *et al.* (2021) in *beels* of West Bengal and Kunda *et al.* (2022) in wetland of Bangladesh. Nevertheless, with the exception of Triparna *et al.* (2021), the majority of them recorded the lowest value of H' during the monsoon, which is consistent with the present findings. During pre-monsoon, the shrinkage of wetlands leading to rise in temperature and reduction in oxygen may expose the fish to stress, thereby leading to mortality (Sarkar *et al*., 2020). It was also noted during the study and has previously been documented by earlier researchers (Pal and Akoma, 2009) that Bansabati *beel* shrank during the pre-monsoon months. This could have caused a decrease in individuals and a corresponding decrease in H' value. It is also supported by low value of evenness index observed in the present study during pre-monsoon.

Evenness, a metric used to determine relative diversity, has a high value when all species in a population are uniformly spread (Aziz *et al.,* 2021). Pielou’s evenness (J’) value usually ranges from 0 (no evenness) to 1 (complete evenness). Previous studies have found moderate to high evenness in several *beels*, with values ranging from 0.561 to 0.951 (Kaur *et al.,* 2017; Aziz *et al.,* 2021; Dua and Parkash, 2009), which is consistent with the findings of the current study. In comparison to winter and pre-monsoon seasons, monsoon and post-monsoon periods had relatively higher levels. Higher values of evenness index during post-monsoon are also reported by earlier researchers (Triparna *et al.,* 2021; Sarkar and Saha, 2021; Kunda *et al.,* 2022). There were no significant seasonal changes ($P>0.05$), indicating that the species were distributed rather evenly throughout the *beel* all year long.

Canonical correspondence analysis has been performed for the entire study period (Figure 4.22). Quantitative environmental variables are indicated by thick green lines and the months are indicated by black dots, diversity indices are plotted in blue colours. The length of the green lines indicates the relative strength of the relationship between that factor and the diversity indices. The Eigen values of axis 2 (horizontally) and axis 1 (vertically) are 1.57×10^{-6} and 0.0002, respectively but the Eigen value of axis 3 (not displayed) is 2.21 X 10^{-8}. CCA plot shows that data of fish diversity indices were connected with environmental characteristics. In January and February (winter season) Shanon weiner diversity index were mainly related to dissolved oxygen and water pH, whereas in September (post monsoon) hardness and alkalinity had a much higher consequence with Margalef's index. Pielou's index were correlated to water temperature in July month (monsoon). The CCA plot also shows that water temperature is negatively correlated with the dissolved oxygen and water pH. Dissolved oxygen in water and water pH are correlated positively. In the current study, the analysis of CCA showed that dissolved oxygen, water temperature, water pH, hardness, alkalinity affected fish diversity indices. Seasonal fluctuations in water quality have been reported to affect fish assemblages in a variety of fish habitats, although water quality was always related to the season and sample period (Abrial *et al*., 2014).

The information generated in this study will serve as a baseline which could be used for conservation and management planning and developing adaptation strategies in future. The Bansabati *beel* has a tremendous potential for fisheries and has a moderate to rich fish variety. Rich native and decorative ichthyofauna, on the other hand, is steadily disappearing and necessitates scientific intervention for long-term ecological advantages. Future planning for conservation and management as well as the creation of adaption strategies may use the data collected by this study as a baseline.

Table 4.37 One way ANOVA to analyse significant differences in Margalef's richness index in Bansabati beel

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	3.00284	3	1.000947	24.83985	0.000209	4.066181
Within Groups	0.322368	8	0.040296			
Total	3.325208	11				

Table 4.38 One way ANOVA to analyse significant differences in Shanon-Weiner index index in Bansabati beel

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.134636	3	0.044879	23.99066	0.000236	4.066181
Within Groups	0.014965	8	0.001871			
Total	0.149601	11				

Table 4.39 One way ANOVA to analyse significant differences in Simpson index in Bansabati beel

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.001152	3	0.000384	5.2375	0.027223	4.066181
Within Groups	0.000587	8	7.33E-05			
Total	0.001739	11				

Table 4.40 One way ANOVA to analyse significant differences in Pielou's evenness index in Bansabati beel

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.001279	3	0.000426	2.708135	0.115555	4.066181
Within Groups	0.001259	8	0.000157			
Total	0.002538	11				

Table 4.41 Species diversity indices in different seasons in Bansabati *beel*

Season	Margalef's richness index	Simpson's diversity index	Shannon and Wiener index	Pielou's evenness index
Pre-monsoon	4.388^{a}	0.890^{a}	2.786^{a}	0.795^{a}
Monsoon	4.334^{a}	0.905^{a}	2.790^{a}	0.817^{a}
Post-monsoon	5.423^{b}	0.918^{ba}	3.018^{b}	0.814^{a}
Winter	5.290^{b}	0.905^{a}	2.977^{b}	0.796^{a}

Mean values bearing different superscripts under each column vary significantly (P<0.05)

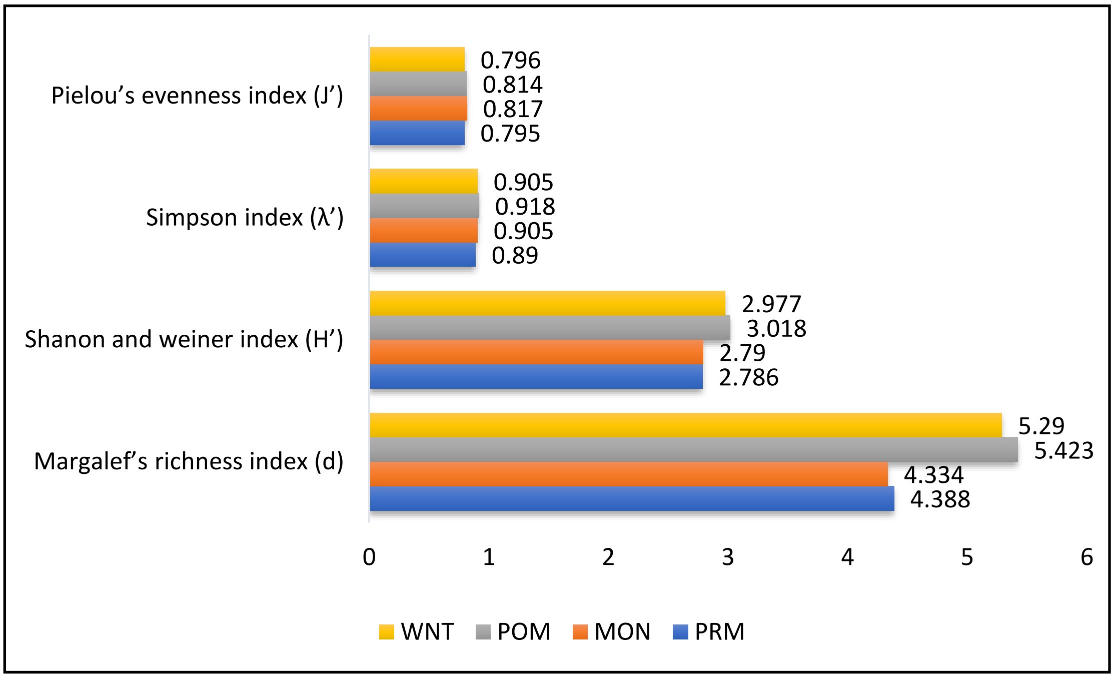


Figure 4.21 Mean values of fish diversity indices during pre-monsoon (PRM), monsoon (MON), post-monsoon (POM) and winter (WNT)

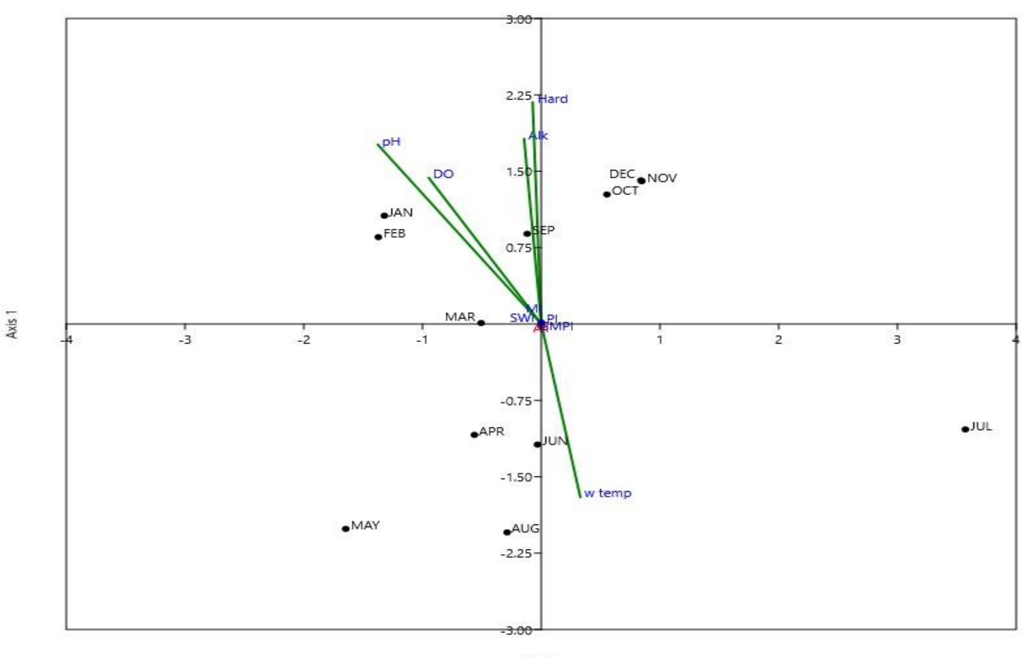


Figure 4.22 Canonical Correspondence analysis (CCA) plot illustrating fish diversity indices, water quality parameters and months

MI- Margalef's richness index, SWI- Shanon-Weiner index, SI- Simpson index, PI- Pielou's evenness index, DO- dissolved oxygen, W temp- water temperature, Hard- hardness, Alk- alkalinity, DEC- December, JAN- January, FEB- February, MAR- March, APR- April, MAY- May, JUN- June, JUL- July, AUG- August, SEP- September, OCT- October, NOV- November

4.8 Evaluation of fish based index of biological integrity

A total of 42 fish species were sampled from the Bansabati *beel* and their categorization based on their status, tolerance level, trophic guild and habitat guild is given in Table 4.42. Based on species richness and composition, 37 species were native, 18 native families, and five species were noted as non-native. Nine species were native minnows, 14 species were intolerant, 18 species were benthic, and 24 species were in the water column habitat.

Table 4.43 shows the site-wise variation in metrics values and IBI assigned scores for the Bansabati *beel*. The number of native species in this wetland ranged from 21 (S1) to 37 (S3); the number of native families ranged from 08 (S1) to 18 (S3); the number of native minnows ranged from 5 (S1; S5) to 8 (S3); the number of benthic species ranged from 8 (S1) to 15 (S3), the number of water column species ranged from 15 (S1) to 22 (S3), the number of intolerant species ranged from 4 (S1) to 13 (S3); the total number of individuals varied from 751 (S5) to 1044 (S3); the percentage of individuals as non-native species varied from 0.21 (S3) to 1.31 (S1); the percentage of fishes with disease and anomalies varied from 0.25 (S3) to 6.32 (S1), all scores ranged from 3 to 5. The percentage (%) of individuals classified as omnivores, herbivores, and top carnivores ranged from 17.24 (S3) to 77.90 (S1) scored within the range of 1 to 5; 4.90 (S1) to 18.67 (S3) scored within the range of 1 to 3; and 17.18 (S1) to 64.08 (S3) scored within the range of 1 to 5 respectively.

In comparison to what was seen in the stress zone (S1, S5), the reference site (S3) had more native species and families. The number of benthic species, water column species, and intolerable species have all decreased in the S1 and S5, according to a comparison of species composition. Additionally, at the stressed site, there were changes in the fishes' trophic composition. The metric percent of individuals classified as omnivores was higher in the stressed site (S1 and S5) than reference site (S3). The amount of diseased, abnormal, or non-native fish was likewise minimal at the reference site (S3) than other sites.

4.8.1 IBI scores and health status of the wetland

The total IBI score of Bansabati *beel* for the study period was estimated by summing up the 12 metric scores (Table 5). The IBI scores varied from 30 (S1; impaired) to 58 (S3; acceptable). The qualitative evaluation of the IBI in the S5 was 42 (marginally impaired) respectively. In order to assess the overall health status of the Bansabati *beel*, the average index score was found to be 43.33, which indicated a 'marginally impaired' condition of the wetland ecosystem.

4.8.2 Selection and validation of IBI metrics

With the help of suitable fish indicator species at the community level, fish assemblages may include the entire ecological integrity of a system, making biological integrity a helpful framework for evaluating the health of the aquatic environment (Fausch *et al*., 1990; Simon *et al*., 2003). The fish-based biotic integrity was developed as a part of the present research to assess ecological health of the Bansabati *beel*, an open wetland.

Open *beel*s are generally characterised by rapid water flow in and out, leading to wide fluctuations in water chemistry, ecological conditions and primary production levels in comparison to closed ones. However, the death and decay of submerged and marginal macrophyte populations due to the rapid influx of water could be advantageous for nutrient recycling (Sugunan *et al*., 2000). Several researchers have documented freshwater ichthyofaunal diversity of West Bengal ranging from 29-267 different species (Barman, 2007; Mogalekar *et al*., 2017) including both native and non-native species as well as primary and secondary freshwater forms. Number of fish species recorded by them varied between 19 in Chaltia *beel* (Sarkar *et al*., 2020) and 54 in Patan wetland (Dey, 2017) with Cyprinidae as the dominant family, which is comparable with the present study. The species richness of fish in the current study demonstrated considerable variance; a measure of biological variety is the number of native species and native families, both of which decline with increasing human disturbances (Karr, 1981; Noss, 1990). But interestingly, the high number of native species and families in the S3 of the study area suggested an intact environment with little human interruption. However, relatively few native species and families were found in S1 and S5, which indicated that the location had considerable levels of organic contamination owing to human interruption. The native fish species such as *Amblypharyngodon mola*, *Chanda nama*, *Pethia conchonius*, *Notopterus notopterus, and Labeo gonius* are abundant despite the fact that it is an open wetland with sporadic connections to the Bhagirathi River and two minor streams with low gradients, Bansloi and Pagla. But Das and Samanta (2006) saw a drastic decline in the number of native species and families in the Hooghly estuary.

It has been shown that the existence of intolerant species populations is an essential indicator of water quality since these species are the first to vanish when a pollution event occurs (Karr 1981). In anthropogenically pressured areas, intolerant fishes are less prevalent and more sporadically dispersed (Ganasan and Hughes, 1998). Due to water quality deterioration induced by domestic sewage, filling up the shallow section of the *beel* and creating a plot for the cultivation of different crops, there may be fewer intolerant species at S1 and S5. Even though S1 and S5 experience human interactions, surface run-off of organic materials into water bodies, disturbance of sediments containing a lot of aquatic plants, or excess nutrient loading through sewage; low water levels, and high temperatures may all cause oxygen depletion in water bodies (Varghese *et al*., 2018). At S5, shrinking of wetlands in the dry season and increased water stress was observed owing to elevated temperature and a consequent drop in oxygen levels (Sarkar *et al*., 2020).

The implementation of canonical correspondence analysis CCA (Figure 4.23) to determine the relationship between environmental characteristics (Table 3) and fish multimetrics indicated the response of fish communities to variable water quality conditions. Number of native species (NS), number of native families (NF), number of native minnows (NM), and number of intolerant species (IS) were mostly determined by the water quality parameters dissolved oxygen (DO) and transparency (TR) suggesting adequate water quality conditions in the *beel* at S3. Karr (1981), Lyons (1992), Abhijna and Kumar (2017) also reported similar results and hence opined. The sensitivity of the fish assemblages to the parameters dissolved oxygen (DO) and transparency (TR) was indicated by the negative relationship between metrics such as percentage of individuals as omnivores (OM) and percentage of individuals with abnormalities or disease (AN) indicating deteriorating water quality at S5 (Karr *et al*., 1986; Hughes *et al*., 1998; Ganasan and Hughes 1998). Hardness (HD) and alkalinity (AL) determined the metrics such as percentage of non-native individuals (NN) at S1 showing severely stressed habitat conditions since the site existed as the segment of the *beel* that is linked to the river.

Parameters pertaining to trophic status and feeding guilds seemed to be quite helpful for developing IBI. Any change in the environment might reduce food availability, which in turn influences food choices. Large populations of omnivores are found in S1 (77.90%), and S5 (63.64%) mostly, and their dominance is most likely a result of the loss of food sources, particularly invertebrates (Karr, 1981), sewage dumping, eutrophication and siltation. Another sign of degraded habitat (S1 and S5) is a drop in the number of intolerant species and an increased number of omnivores.

Rapid water exchange in the S1, where the river channel links to the *beel*, prevents plankton species from colonising and stabilising (Sugunan *et al*., 2000). As a consequence, S1 might have recorded fewer herbivores. Due to the open *beel* structure of Bansabati, the addition of organic waste may encourage the growth and production of phytoplankton and zooplankton at S3, where the environment is just starting to colonise, leading to greater ichthyofaunal availability. Similar findings were made by Ganasan and Hughes (1998), Hughes and Oberdorff (1998), showing that the omnivorous guild prefers to grow in deteriorated environments. Furthermore, top carnivore species distinguish between high and moderate water quality, and they often diminish in response to disturbance (Ganasan and Hughes, 1998).

At S1 and S5, a decrease in benthic species and water column species is a sign that the ecology is becoming worse. Species inhabiting the water column are energetic swimmers that feed on drifting and surface invertebrates. Changes in water quality and habitat structure, such as siltation, turbidity, and oxygen depletion, may affect benthic and water column organisms (Ganasan and Hughes, 1998; Das and Samanta, 2006). It is also noteworthy to mention that the populations of certain fish species is steadily declining. According to the findings of the present study, Bansabati *beel*, with an overall average IBI value of 43.33, could be categorised as a "marginally impaired" condition. Furthermore, S1 with IBI value of 30 and S5 with IBI value of 42 could be categorised as "impaired" and "marginally impaired", respectively. The IBI score is at its lowest (30) in S1, particularly among those who have abnormalities or diseases. In accordance with Ganasan and Hughes (1998), it is believed that both the reference condition data from minimally affected locations and the metric scoring criteria need additional analysis. IBI ratings and qualitative assessments as a consequence will be too high to encourage waterbody conservation or rehabilitation. However, as noted by Ganasan and Hughes (1998), it could be essential to restore some of the worst conditions in an ecoregion by using damaged reference sites.

Table 4.42 Classification of fishes collected during the study period from the Bansabati *beel*

SL. NO.	Name of the species	Family	Status	Tolerance	Guilds	
					Trophic	Habitat
1.	*Labeo bata* (Hamilton,1822)	Cyprinidae	N	INT	H	B
2.	*Labeo rohita* (Hamilton,1822)	Cyprinidae	N		H	WC
3.	*Labeo catla* (Hamilton,1822)	Cyprinidae	N		H	-
4.	*Cirrhinus mrigala* (Hamilton,1822)	Cyprinidae	N	INT	O	B
5.	*Labeo calbasu* (Hamilton,1822)	Cyprinidae	N		O	WC
6.	*Pethia ticto* (Hamilton,1822)	Cyprinidae	N, NM	INT	O	WC
7.	*Labeo gonius* (Hamilton,1822)	Cyprinidae	N		H	WC
8.	*Cyprinus carpio* Linnaeus, 1758	Cyprinidae	NN	INT	O	B
9.	*Systomus sarana* (Hamilton, 1822)	Cyprinidae	N	INT	O	WC
10.	*Puntius sophore* (Hamilton, 1822)	Cyprinidae	N, NM		O	WC
11.	*Pethia conchonius* (Hamilton, 1822)	Cyprinidae	N, NM		O	WC
12.	*Hypophthalmichthys molitrix* (Valenciennes,1844)	Xenocyprididae	NN		H	-
13.	*Ctenopharyngodon idella* (Valenciennes, 1844)	Xenocyprididae	NN		H	WC
14.	*Rasbora danriconius* (Hamilton, 1822)	Danionidae	N, NM	INT	O	-
15.	*Amblypharyngodon mola* (Hamilton, 1822)	Danionidae	N, NM		H	-
16.	*Lepidocephalichthys guntea* (Hamilton, 1822)	Cobitidae	N, NM		O	B
17.	*Oreochromis mossambicus* (Peters, 1852)	Cichlidae	NN		O	WC
18.	*Oreochromis niloticus* (Linnaeus, 1758)	Cichlidae	NN		O	WC
19.	*Glossogobius giuris* (Hamilton, 1822)	Gobiidae	N		C	B
20.	*Channa orientalis* Bloch & Schneider, 1801	Channidae	N	INT	C	B
21.	*Channa punctata* (Bloch, 1793)	Channidae	N		C	B

SL. NO.	Name of the species	Family	Status	Tolerance	Guilds	
					Trophic	Habitat
22.	*Channa striata* (Bloch, 1793)	Channidae	N		C	B
23.	*Channa marulius* (Hamilton, 1822)	Channidae	N		C	B
24.	*Chanda nama* Hamilton, 1822	Ambassidae	N, NM	INT	C	WC
25.	*Parambassis ranga* (Hamilton, 1822)	Ambassidae	N, NM		C	WC
26.	*Anabas testudineus* (Bloch, 1792)	Anabantidae	N		C	WC
27.	*Nandus nandus* (Hamilton, 1822)	Nandidae	N		C	WC
28.	*Trichogaster fasciata* Bloch & Schneider, 1801	Osphronemida	N, NM		O	WC
29.	*Heteropneustes fossilis* (Bloch, 1794)	Heteropneustidae	N		C	B
30.	*Clarias magur* (Hamilton, 1822)	Clariidae	N		C	B
31.	*Mystus vittatus* (Bloch, 1794)	Bagridae	N		C	B
32.	*Sperata aor* (Hamilton, 1822)	Bagridae	N	INT	C	B
33.	*Wallago attu* (Bloch & Schneider, 1801)	Siluridae	N		C	B
34.	*Ompok pabda* (Hamilton, 1822)	Siluridae	N	INT	C	B
35.	*Ailia coila* (Hamilton, 1822)	Ailiidae	N		O	WC
36.	*Mastacembelus armatus* (Lacepede, 1800)	Mastacembelidae	N	INT	C	WC
37.	*Macrognathus aral* (Bloch & Schneider, 1801)	Mastacembelidae	N		C	WC
38.	*Macrognathus pancalus* Hamilton, 1822	Mastacembelidae	N		O	WC
39.	*Ophichthys cuchia* (Hamilton, 1822)	Synbranchidae	N	INT	C	B
40.	*Notopterus notopterus* (Pallas, 1769)	Notopteridae	N		C	B
41.	*Xenentodon cancila* (Hamilton, 1822)	Belonidae	N	INT	C	-
42.	*Leiodon cutcutia* (Hamilton, 1822)	Tetraodontidae	N	INT	O	B

Status symbol include: N = Native, NN = Non-native, NM = Native minnow; Tolerance symbol: INT = Intolerant species; Habitat guild symbols: B = Benthic species, WC = Water column species; Trophic guild symbols: H = Herbivores, O = Omnivores, C = Top carnivores

Table 4.43 Variations in the metric value and assigned scores for each metric of the index of biotic integrity for the Bansabati *beel*

Metric	Site 1	Site 3	Site 5
Number of native species	21(3)	37(5)	25(3)
Number of native families	08(3)	18(5)	10(3)
Number of native minnows	5(3)	8(5)	5(3)
Number of water column species	15(3)	22(5)	16(5)
Number of benthic species	8(3)	15(5)	12(5)
Number of intolerant species	4(3)	13(5)	6(3)
Percentage individuals as omnivores	77.90(1)	17.24(5)	63.64(3)
Percentage individuals as herbivores	4.90(1)	18.67(3)	10.25(3)
Percentage individuals as top carnivores	17.18(1)	64.08(5)	26.09(3)
Total number of individuals	937(3)	1044(5)	751(3)
Percentage individuals as non-native	1.31(3)	0.21(5)	0.72(5)
Percentage individuals with anomalies or disease	6.32(3)	0.25(5)	4.72(3)
Total	**30 (impaired)**	**58 (acceptable)**	**42 (marginally impaired)**

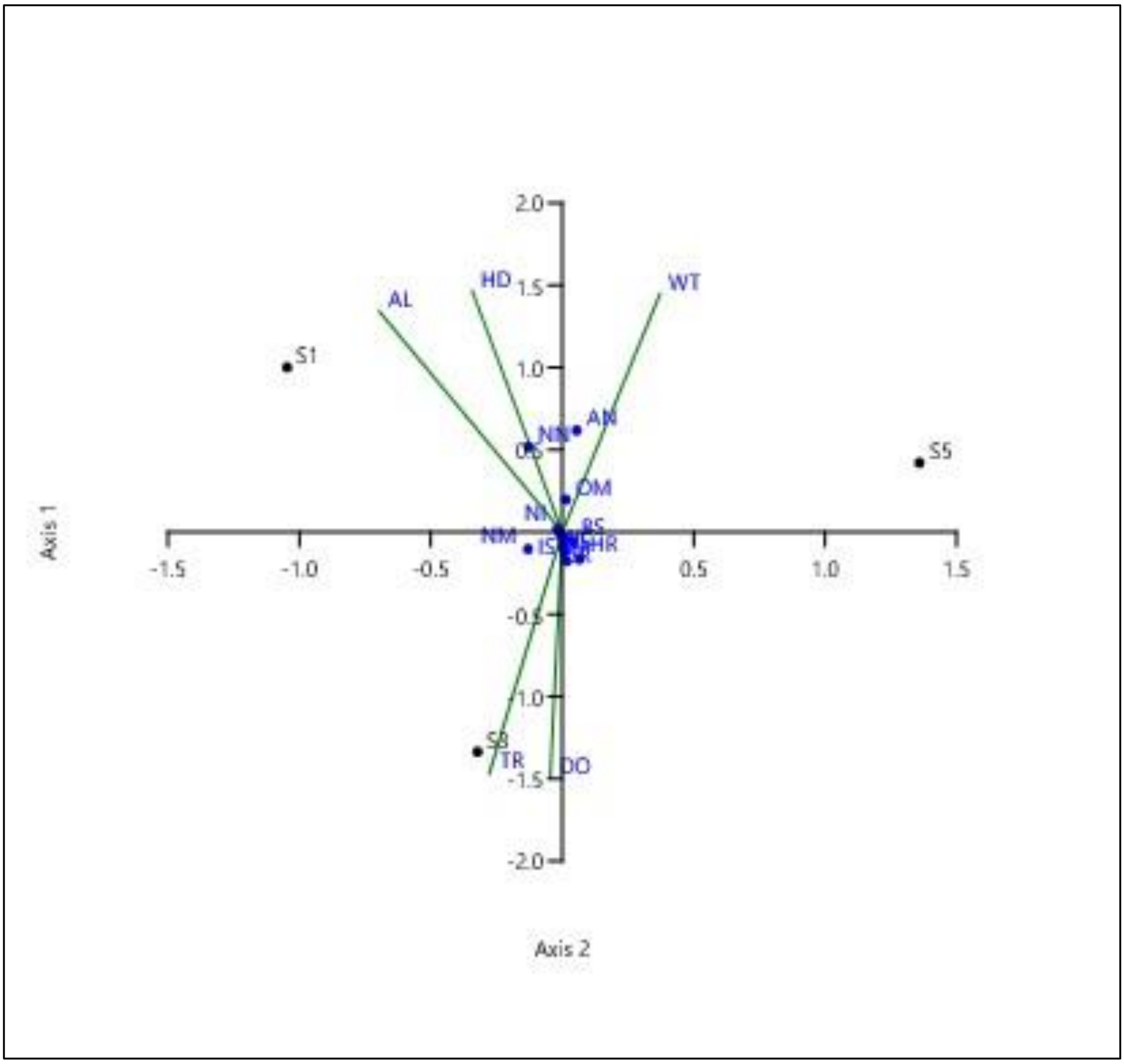


Fig 4.23 Canonical Correspondence analysis (CCA) plot illustrating candidate fish multimetrics, environmental variables and sites

Note- WT- water temperature, TR- transparency, DO- dissolved oxygen, AL- alkalinity, HD- hardness, NS- number of native species, NF- number of native families, NM- number of native minnows, WC- number of water column species, BS- number of benthic species, IS- number of intolerant species, OM- percentage individuals as omnivores, HR- percentage individuals as herbivores, CR- percentage individuals as top carnivores, NI- total number of individuals, NN- percentage individuals as non-native, AN- percentage individuals with anomalies or disease.

4.9 Traditional Fishing practices

A thorough understanding of fishing craft and gear is imperative for understanding the present exploitation system of natural fisheries and also for making suitable improvement. A diverse range of fishing crafts and gears had been evolved over a long period of time by the fishermen of Bansabati beel, to capture a wide range of fish species. Fishing craft and gears adopted by fishermen community of the lake were simple, mostly old fashioned and indigenous. The local fishermen apply unique indigenous knowledge of fishing methods in particular areas to rational exploitation of the fisheries resources to support their livelihood. Detailed photographic description of this operated craft and gear in this studied water body is presented in Plate 4.7 and Plate 4.8.

4.9.1 Fishing craft

The survey regarding the fishing craft used in Bansabati beel revealed that fishermen of the study area have been using 2 different types of fishing craft to catch fishes from the beel.

4.9.1.1 Tin Boat

It is a common simple and mostly operated man made fishing craft in this studied beel. It is made by the readily available tin to construct this boat. With a help of single piece of wooden plank, it is constructed and it has no identifying anterior and posterior portion. The average length, breadth and height were as 6.5ft and 0.5- 1.5 ft, 1-1.5 ft respectively. Only one person can operate the boat by using wooden stick. One of the major drawbacks of this boat is water gets easily into the boat if the wage loading is too high. Due to less height of the boat the chance of turnover is more common phenomenal in deep waters. Gears like Current Jal, Phasa Jal, etc. are commonly operated from the boat. The carrying capacity of tin boat is about 10-15 Kg in weight.

4.9.1.2 Nouka

The Nouka is most commonly operated fishing craft in this studied beel. This boat is non mechanized, manually operated boat mainly made up with wooden plank of Shal, Babla and Segun. It has flat bottom and oval in shape. The anterior portion is blunt and posterior part is moderately pointed. . This wooden locally manufactured boat is painted by synthetic paints for protection against water. The average length, breadth and height were as 28.12ft and 5-5.5ft, 3-3.5ftrespectively. Two fishermen untimely can propel this boat with the help of bamboo stick at the two end points. The nouka is used for the operation of gears like Current Jal, Phasa Jal and traps. The carrying capacity of Nauka is about 80-120 Kg in weight.

4.9.2 Fishing gear

The survey regarding the fishing gears used in Bansabati beel revealed that fishermen of the study area have been using six different types of fishing gears to catch fishes for their daily earnings. The indigenously used fishing devices, their construction and the methods of applications are described here.

4.9.2.1 Phasa Jal

This is a type of gill net used in shallow area of the beel by local fishermen. They are single walled nets weir mesh size 2-12 cm and length varies from 10-50 cm. It is mainly operated during the night time, from evening to early morning. The target species of fish are *Nandus nandus, Chanda nama, Trichogaster fasciata, Mystus vittatus, Puntius sophore, Pethia conchonius,* IMC.

4.9.2.2 Current Jal

It is one type of single wall monofilament gill net which is widely used by the local fishermen of the beel. The mesh size (1.5 – 8 cm) of this net depends on the size of the fishes are to be caught. This net is mainly operated at the surface of the water body and it hauled from the boat after few hours of its installation. Fishes like *Chanda nama*, *Trichogaster fasciata*, *Rasbora daniconius, Mystus vittatus*, *Nandus nandus* are caught during its operation.

4.9.2.3 Chak Jal

It is a kind of falling gear having a conical net fitted inside a bamboo frame. The bamboo frame is ring like structure fitted with four bamboo poles which are tied together at the top to form a cone. It is usually operated throughout the year especially when water level are low in the vegetation infested areas of the lake. It is operated by a single person. When the fishes are located, the fisherman thrusts a bamboo stick into the bottom so that the fishes jumps out of the mud and at that time operating person just drops the lower part of the net which is tied to the circular frame into the water, while holding the upper portion of the net (2 – 10 cm). As the fishes get trapped in the nets, the upper part is untied and the fishes are taken out from the net. Mostly *Puntius sophore*, *Chanda nama*, *Trichogaster fasciata*, *Rasbora daniconius* are mainly caught during its operation.

4.9.2.4 Trap (Kurel)

It is an efficient and most popular indigenous gear for fish trapping. It is operated from fishing boat during day hours and throughout the year in the lake. *Kurel* is a domes shaped and made up of six to eight bamboo sticks, arranged in circle and tightened to each other with the help of nylon rope. Bamboo rods are covered by nylon mesh measuring 2.0 to 3.0 cm. After assembly, the circumference of the dome is 5-10 feet and the height 10 feet. The top of the gear is provided with a circular opening of about 1 to 2 ft in diameter for entrance of fisher in trap (Fig. 6). The catch of the gear includes major carps like *Labeo rohita*, *Catla catla* and *Cirhinnus mrigala*.

The operation of the trap is very interesting during fishing. The fishers carry the Kurail on boat and they drub by the wooden oar (patwar) on the surface water and quietly observe the water movement to determine the presence of big fish. If the fishes move very fastly they cover the area by Kurel in the water. The fishermen enter in the Kurail from the top mouth and collect the catch.

4.9.2.5 Scoop net

This scoop net variety made up with mosquito or nylon net. It is mainly operated in weed infested area and handling from dyke of the lake. It is mounted on long bamboo frame with various shapes such as triangle, circular and also trapezoidal shape. It is an age old easy fishing practice that could be handled by anyone with minimum effort. Fishes like *Anabas testudineus*, *Clarias magur*, *Channa punctatus, etc.* are caught during the fishing.

4.9.2.6 Borshi

It is an angling fishing method which is operated by anyone starting from children to an old man. This is mainly consisting of bamboo pole of about 2-2.5m long. At the tip of this pole is tied with 2-3 m length of nylon or cotton twine along with a baited hook. A float is also attached with the twine to make an observation over fish movement after they are entangled into the hook. For proper hanging inside the water, a lead weight is attached to the line just to avoid drifting of the angling. Mainly pasted flour with insects, earthworms is used as baits to attract the fishes. *Clarias magur*, *Channa striatus, Ophichthys cuchia etc* are the main species which are caught during their operation.

4.9.2.7 Box trap

It is a fishing device in which fish are enticed by enclosures where they are guided to enter the trap. It is the chief gear used for fishing in this beel to catch different species and sizes of fish. These are made of split bamboo sticks woven with the long pliable stems of a creeper. Catching fish through traps is a passive process. Baits are kept inside the traps sometimes to attract fish. The rectangular shape basket trap is the most extensively operated gear and accounts for major part of the catches. It has two vertical openings, one on each long side. Each vertical opening is fixed with a series of inwardly directed, short, pointed bamboo sticks interwoven in such a way that the tips of the two series of splints cross each other. This type of arrangement only permits easy entry of the fish but not their exit. IMC carps are the main species which are caught during their operation.

4.10 Marketing Channel

The marketing channel is defined as the path through which the fish catch passes starting from the fisher to the consumer (Brunswick, 2014) including all the market intermediaries (fishers, dealers, wholesalers, retailers and vendors) who handle and pass on the catch. All the marketing channels noticed in the beel fisheries invariably involve middlemen. The channel for sending fish to outside was different from the local supply. For local markets, small traders purchase fish from beel fishers and sell to retailers or directly to consumer. For outside, wholesaler purchased the fish from small traders and sent it to other distant markets. The retailers retail them into urban market or through itinerant marketing to consumers.

4.11 Fisheries

Bansabati beel is an open-access natural water body. In the beel, only capture fisheries are practiced depending on the automatic recruitment and auto-stocking during the flood. Local residents are directly using the beel with a subsistence and partly marketing relationship. Fishing activity is carried out throughout the year. The beel was initially leased by Co-operative society but now transferred to the Gram Panchayatas. About 250-300 fisherman from nearby villages viz., Bansabati, Aluani, Nazirpur, Takshak have been engaged in fishing in this beel from the days of their ancestors. It has been observed that three groups of fishers are known to fish in the Bansabati beel; i) neighbourhood group, who generally fish with small gears for self consumption, ii) island fishers, who fish only in fishing seasons and iii) fishers from outside places who fish only in the peak season with large gears.

Tin Boat **Nouka and Trap (Kurel)**

Phasa Jal **Current Jal**

Chak Jal **Scoop net**

Box trap **Borshi**

Plate 4.4 Fishing crafts and gears operated at Bansabati beel

4.12 Trophic status

4.12.1 Carlson's Trophic State Index (TSI)

A prominent approach for describing the trophic condition or general health of a lake is Carlson's Trophic State Index (TSI) which makes use of measurements for phosphorus, chlorophyll a, and Secchi's disc transparency. The Carlson's trophic status index was be calculated using the average values of these three parameters' TSI (Carlson, 1977).

4.12.2 Trophic status of the Bansabati beel

The range as well as mean value of the Carlson's trophic state index (CTSI) of the Lake is presented in Table 4.45. The monthly variations of TSI based on total phosphorous (TP) was higher in monsoon months, it might be due to entry of domestic waste, detergent and agricultural run-off which brought large amount of phosphorus into the lake water, which is in agreement with the findings of Srinivas and Aruna (2018). It is also noteworthy to mention here that PO_4-P levels were higher during monsoon in the present study. However, in winter months, it was lower in value which could be due to absorption of phosphorous by phytoplankton and other aquatic plants. Similar observations were made by Javeed *et al.* (2019). TSI was higher in the post monsoon season, based on Chlorophyll-a (CHL-a) due to higher density in phytoplankton community in these months. It might be due to settlement and availability of more nutrients (Ghosh and Biswas, 2015). But in the monsoon season, value decreased which might be due to runoff from the nearby field into the lake could have changed the physico-chemical properties of water leading to physiological stress on plankton community. This could directly effect on chlorophyll-a value which is in agreement with earlier report of Singh *et al.* (2017). The TSI was higher in monsoon and post monsoon season, based on Secchi depth (SD).

The overall mean TSI value was in order of TSI-SD> TSI-Chla> TSI-TP. Overall TSI value based on all three parameters considering all months is presented in (Table 4.45). The results obtained from the current investigation revealed that overall mean value of Carlson's trophic state index (CTSI) of the Bansabati beel was 53.85 (Table 4.45) which suggested that floodplain wetland may be classified to be in the transition phase from mesotrophy to eutrophy. However according to (Melcher, 2013); this lake may be classified as Strongly mesotrophic. Puthiyottil *et al.* (2021) reported that the values of

CTSI of Katiganga, an open beel in Gangetic basin, ranged from 50 to 55, which very close to the present study. The TSI value based on the three parameters was almost similar in all the months at five stations respectively except during the monsoon months. The nutrients might enter into the lake as agricultural runoff, sewage or waste water from localities leading to over enrichment of nutrients into the lake water resulting in higher value in monsoon months. Similar kind of observation was reported by Ramesh and Krishnaiah (2014) and Ghosh and Biswas (2015). Due to the above reason, growth of macrophytes in the lake increases causing biological oxygen demand to go up which in turn lead the lake towards a fall in dissolve oxygen level (anoxic conditions) ranging 4.11 to 4.65 mg/l in monsoon months. However, Patra *et al.* (2016) studied trophic state index of Nalban Lake of East Kolkata Wetland which indicates that the lake is appeared to be eutrophic to hyper eutrophic conditions.

Therefore, the existing results of present study revealed that Bansabati beel needs scientific intervention for its conservation management and measures should be taken on urgent basis in order to intercept the increasing trend in eutrophication, and for the restoration of water quality and integrated lake ecosystem.

Table 4.45 Overall monthly variation in trophic status index of Bansabati beel

Year	Months	TSI-TP	TSI-Chla	TSI-SD	CTSI
2020	December	45.17	51.82	58.89	51.96
2021	January	43.00	52.28	57.61	50.96
	February	44.31	52.68	57.61	51.53
	March	48.32	51.36	58.23	52.63
	April	52.90	51.09	58.62	54.20
	May	55.50	50.18	59.16	54.94
	June	56.45	49.46	59.71	55.20
	July	57.91	48.56	62.00	56.15
	August	56.68	48.07	63.39	56.04
	September	54.83	49.91	63.03	55.92
	October	50.45	50.85	61.04	54.11
	November	46.91	51.14	59.71	52.58
	Average	51.03	50.61	59.91	**53.85**

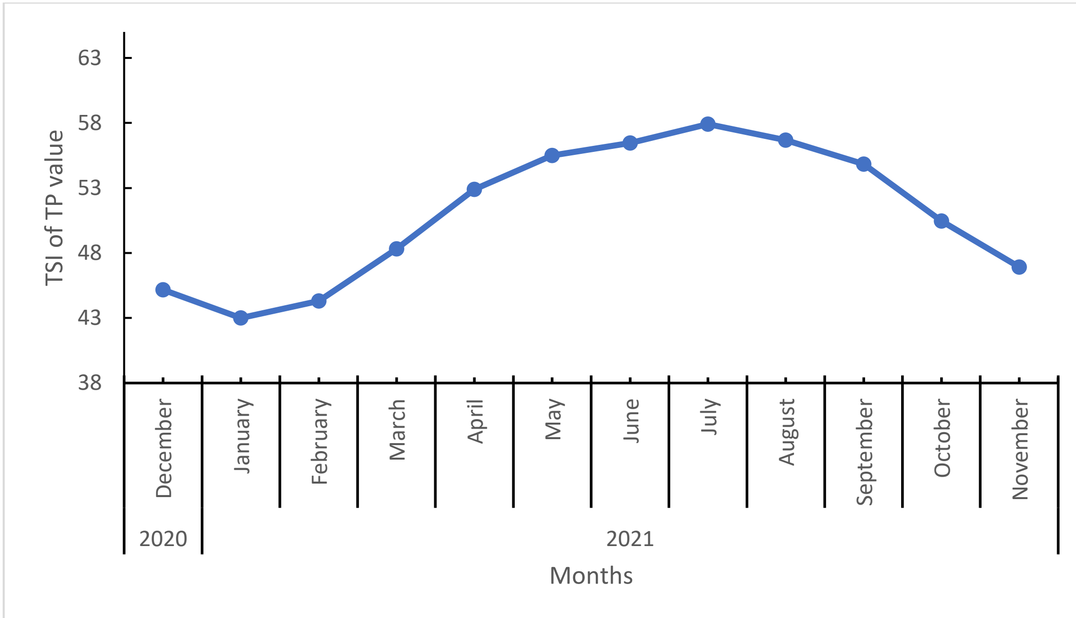


Figure 4.24 Seasonal variation in TSI based on total phosphorus (TP) concentration of Bansabati beel

Figure 4.25 Seasonal variation in TSI based on chlorophyll-a concentration of Bansabati beel

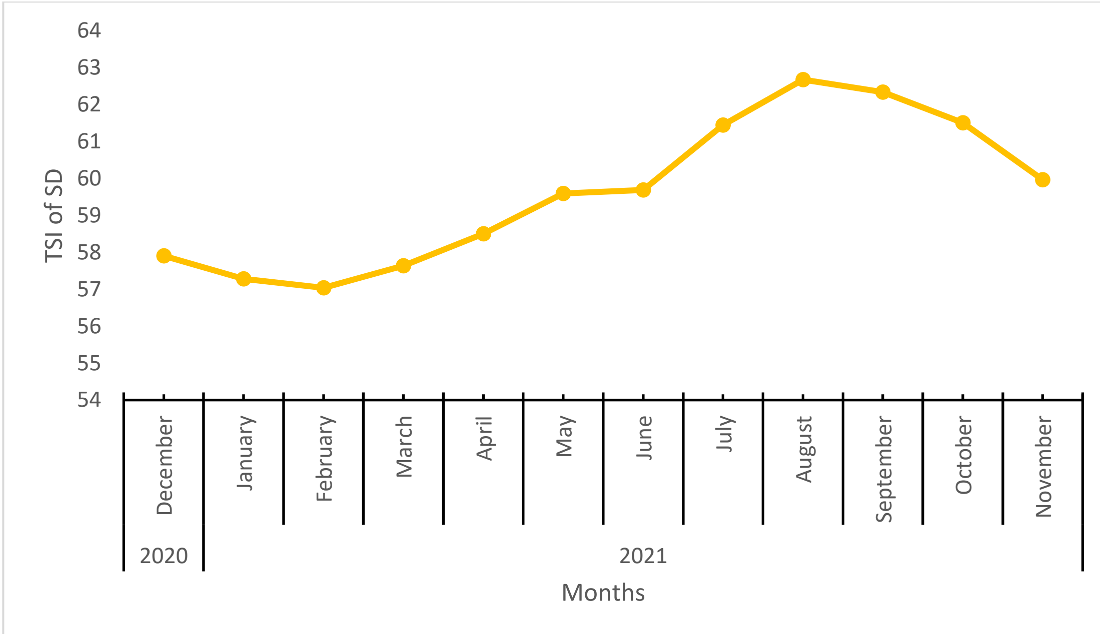


Figure 4.26 Seasonal variation in TSI based on secchi disc depth (SD) of Bansabati beel

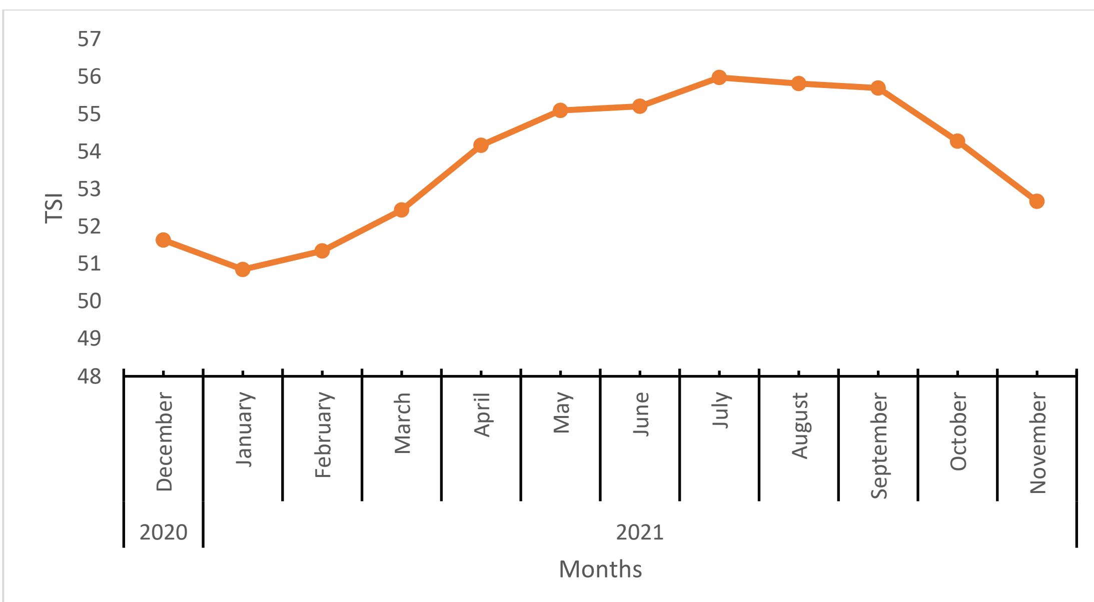


Figure 4.27 Overall monthly variation in Carlson's Trophic State Index (TSI) of Bansabati beel

Chapter 5

SUMMARY AND CONCLUSION

5. SUMMARY AND CONCLUSION

Bansabati *beel*, an open wetland situated at the margin of Suti-I and Raghunathganj-I Blocks of Murshidabad district with an area of 500 ha, was chosen purposively for the present investigation. It occurs in the riverine floodplain of the Ganga-Bhagirathi River system. Two small and low-gradient streams, Bansloi and Pagla originating from the Santhal-Pargana highland of the Chotonagpur plateau drain into the *beel.*

Present study was conducted to analyze ichthyofaunal diversity in the Bansabati beel by ecological and biological approaches from December, 2020 to November, 2021. The main objectives of the study were,
The salient findings have been summarized below,

1. A total of 42 species of fish belonging to 9 orders, 21 families and 32 genera were documented during the study period. With eleven species, the Cyprinidae family was the dominant, followed by Channidae (four species) and Mastacembelidae (three species). Xenocyprididae, Danionidae, Cichlidae, Bagridae, Ambassidae and Siluridae had two species each. There were some families which were the rarest, *viz*., Cobitidae, Nandidae, Gobiidae, Osphronemidae, Anabantidae, Clariidae, Heteropneustidae, Ailiidae, Synbranchidae, Belonidae, Notopteridae and Tetraodontidae, which were collectively grouped as miscellaneous. Among the 42 species recorded in the present study, 24 (57.14%) were abundantly available, 4 (9.52%) were commonly available, 9 (21.42%) were moderately available and 5 (11.90%) were rarely available.
2. The percentage composition of carnivores was higher (48%) followed by omnivores (36%) and herbivores (17%).
3. The trophic level of fish varied between 2.0 and 4.5 with *Channa marulius* emerging as the top-most predator in the *beel*. The other top carnivore fish included *Xenentodon cancila* (3.9), *Nandus nandus* (3.9), *Ophichthys cuchia* (3.8), *Ompok pabda* (3.8), *Channa orientalis* (3.8) and *Channa punctata* (3.8)
4. The IUCN Red List (IUCN, 2022) status of fish species of Bansabati *beel* inferred that one species (2.38%) named *Clarias magur* was categorized as ‘Endangered’ (EN), three species, viz., *Wallago attu*, *Oreochromis mossambicus* and *C. carpio*

were 'Vulnerable' (VU) comprising 7.14% of the listed fish. Three species (7.14%) were 'Near threatened' (NT), namely *O. pabda, H. molitrix* and *Ailia coila*. Thirty-five of the listed fish comprising 83.33% were 'Least Concern' (LC).

5. The corresponding mean values of Margalef's richness of the fish fauna were 4.334 to 5.423 in monsoon and post-monsoon respectively.
6. The highest Simpson diversity index value (0.918) was observed during post-monsoon and the least during pre-monsoon (0.890).
7. In the present study, pre-monsoon recorded lowest of Shannon-Wiener diversity index H' (2.786) and post-monsoon witnessed the highest value (3.018).
8. Pielou's evenness (J') value ranges between 0.795 in pre-monsoon and 0.817 in monsoon.
9. The total IBI score of Bansabati beel for the study period was estimated by summing up the 12 metric scores. The IBI scores varied from 30 (S1; impaired) to 58 (S3; acceptable). The qualitative evaluation of the IBI in the S5 was 42 (marginally impaired) respectively. In order to assess the overall health status of the Bansabati beel, the average index score was found to be 43.33, which indicated a 'marginally impaired' condition of the wetland ecosystem.
10. All of the examined physicochemical characteristics of water, including its temperature, transparency, total dissolved solids, pH, dissolved oxygen level, total alkalinity, total hardness, nitrate-nitrogen, and phosphate-phosphorus content, were within the normal range.
11. Soil quality of Bansabati beel revealed that all parameters studied (pH and Organic Carbon, C/N ratio) were well within the tolerable limits of freshwater fishes.
12. A total of 18 phytoplankton species were identified at Bansabati beel from all different five sites throughout the study period belonging to six groups of phytoplankton viz. Chlorophyceae, Bacillariophyceae, Cyanophyceae, Euglenophyceae and Zygnematophyceae.
13. During the study period, a total of 08 species of macrophytes were recorded. The floristic composition shows that the vegetation of macrophytes in Bansabati beel includes 4 species (50%) were submerged macrophytes, 4 species (50%) were free floating. The dominant family was Pontedericaceae.

14. A diverse range of fishing crafts (Tin boat, Nouka) and gears (Phasa jal, Current Jal, Chak jal, Scoop net, Box trap, Borshi, Kurel) had been evolved over a long period of time by the fishermen of Bansabati beel, to capture a wide range of fish species.
15. Based on the Carlson's trophic state index (CTSI) value of the three parameters like, total phosphorous (TP), chlorophyll –a (CHL-a) and Secchi depth (SD), the overall trophic status of the Bansabati beel was 53.85.

The current study found that fish populations of the Bansabati beel are declining, most likely due to habitat loss, the use of small mesh sized fishing gear, and overfishing. As a result, scientific intervention is urgently required, and beel should be prioritised for ecosystem-based management involving stakeholders, exploring the possibilities of stocking and thus culture-cum-capture fishery, use of appropriate mesh size, awareness among local fishers, and, most importantly, the formation of cooperative societies to monitor fishing activities.

The information generated in this study will serve as a baseline which could be used for conservation, management and planning adaptation strategies in future. The Bansabati beel has a tremendous potential for fisheries and has a moderate to rich fish variety. Rich native and ornamental ichthyofauna, on the other hand, is steadily disappearing and necessitates scientific intervention for long-term ecological advantages.

Chapter 6

FUTURE SCOPE OF RESEARCH

6. FUTURE SCOPE OF RESEARCH

- Conservation value and status of fishes of Bansabati beel.
- Though it is a preliminary study, the present database can be used as reference site in future to calculate the index of biotic integrity.
- Integrative study on species pattern including beel and the connected rivers.
- Ecosystem modelling like, ecopath with ecosim to study energy balance.

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RESEARCH PUBLICATIONS

PUBLICATIONS

List of publications communicated based on the thesis work

Sl. No.	Title of the paper	Authors	Title of the Journal (NAAS)	Remarks/Status
1.	Ichthyofaunal diversity of Bansabati beel - An open wetland in Murshidabad, West Bengal	Arghya Kamal Mondal, Nagesh T. Srinivasan, Sudhir Kumar Das, Samarendra Behera, Bipul Kumar Das, T. Jawahar Abraham	Journal of Inland Fisheries Society of India (5.71)	**Accepted**
2	Evaluation of fish based index of biological integrity of a floodplain wetland of the Gangetic basin, West Bengal, India	Arghya Kamal Mondal, Nagesh T. Srinivasan, T. Jawahar Abraham, Samarendra Behera, Sudhir Kumar Das, Sagarika Das, Aishika Banerjee	Tropical Ecology (6.85)	**Communicated (under review**)

Ichthyofaunal diversity of Bansabati *beel* - an open wetland in Murshidabad, West Bengal

Abstract A basic understanding of the diversity of ichthyofauna is essential in order to manage and safeguard them and to sustain the health of an aquatic ecosystem. The present study investigated the ichthyofaunal diversity of Bansabati *beel*, an open wetland, in Murshidabad district, West Bengal from December 2020 to November 2021. Fish were sampled every month to evaluate species diversity, abundance and trophic guild. Species richness index, Simpson's diversity index, Shannon-Wiener's diversity index and Pielou's evenness index were used to analyse fish diversity. A total of 42 fish species belonging to 21 families were recorded with the dominance of Cyprinidae. Carnivores (47%) dominated the trophic guild followed by omnivores (36%) and herbivores (17%). Three fish species each were designated as "Vulnerable" and "Near threatened" on the IUCN Red List, while one fish species was categorised as "Endangered." Margalef's richness index (4.334-5.423), Shannon-Wiener index (2.786 -3.018), Simpson's diversity index (0.890 - 0.918) and Pilou's evenness (0.795-0.817) values revealed that the *beel* has moderate to high fish diversity and evenness. Additionally, it was noted that the fish population in the *beel* has been steadily declining. In order to maintain biodiversity and reap long-term ecological advantages, the current study recommended ecosystem protection.

Keywords Fish diversity indices, trophic guild; floodplain wetland; Gangetic delta; conservation.

Introduction

Wetlands are regarded as one of the most important life-supporting and producing ecosystems on the planet due to their enormous floral and faunal diversities (Chandrakar and Dhuria, 2020). They also impart significant ecological services and support fisheries and aquaculture activities, besides being crucial for biodiversity conservation (Panthi *et al.*, 2014) thereby maintaining ecological integrity (Kumar *et al.*, 2019; Debnath *et al.*, 2022). Unfortunately, such exquisite wetlands are reeling under anthropogenic stress. Conversion of wetlands into agricultural fields or other commercial purposes has not only threatened rich biodiversity (Bhakta and Bandyopadhyay, 2008; Chowdhury and Nandi, 2014) but also wetland ecosystems. Ramsar convention on wetlands is an international treaty signed in 1971 for international cooperation on the conservation of wetlands and their resources (Kumar *et al*., 2021). The most prevalent type of freshwater wetlands, known as floodplain wetlands, are located in low-lying areas near to large rivers with fluvial landscapes that frequently flood due to overflow from the main river channel (Sugunan *et al.,* 2000; Sarkar *et al.,* 2021) and are locally known as '*beel*' (Chattoraj *et al.,* 2016; Khongngain *et al*., 2017). They are increasingly understood to be essential for maintaining the ecological balance of nearby ecosystems (Chakraborty and Nur, 2009; Mondal and Roy, 2014). West Bengal is provided with 0.61 million ha of freshwater resources, out of which 0.41 lakh ha are *beel*s and *boars* (Bandyopadhyay *et al*., 2014) enriched with diverse indigenous ichthyofaunal composition that could form a vital source of fisheries or ground for aquaculture. A perusal of the literature suggested that these native fish species are on the verge of decline due to habitat loss, invasive species introduction, overexploitation and use of destructive fishing methods along with agricultural runoff leading to environmental and habitat degradation (Chakraborty *et al*., 2006; Siddik *et al*., 2014; Saha and Pal, 2019; Sarkar *et al.,* 2021). Knowledge of species composition, fish faunal distribution pattern, and their conservation status are critically necessary in order to design approaches for the revival of such valuable and ecologically relevant systems (Mogalekar *et al.,* 2017).

The river Ganga, its tributaries and distributaries collectively form the Gangetic plains of West Bengal, which is enriched with numerous floodplain wetlands along the riverine stretches of Hooghly, Bhagirathi, Churni, Jalangi, Torsha, Pagla and others. According to Das *et al*. (2020), the wetland area of Murshidabad has decreased from 0.28 lakh ha in 2001 to 0.06 lakh ha in 2020. Seasonal water logging, floodplains and marshes are most common in this region (Sugunan *et al.,* 2000). Fish and fisheries of *beel*s of Murshidabad have been studied by Sugunan *et al.* (2000) in Baloon *beel*, Mistry (2016) in Ahiran Lake, Bhattacharyya *et al.* (2017) in Bishnupur *beel* and Sarkar *et al.* (2020) in Chaltia *beel*. Bansabati *beel*, an open wetland situated at the margin of Suti-I and Raghunathganj-I Blocks of Murshidabad district, is one of the largest wetlands in Murshidabad district (Mondal, 2012). Despite its significance, there is a dearth of comprehensive biological and ecological knowledge, with the exception of Mondal (2012), who covered specific geographic elements and water flow patterns of the *beel*. Therefore, the goal of the current study – the first of its kind for the Bansabati *beel* – was to investigate fish diversity and generate baseline data that would aid in developing pertinent management strategies for the *beel*.

Materials and methods

Study area

Bansabati *beel* (24°27' 46" to 24°28' 20" N and 87°59' 22" to 88°00' 27"E), an open wetland situated at the margin of Suti-I and Raghunathganj-I Blocks of Murshidabad district with an area of 500 ha, was chosen purposively for the present investigation (Figure 1). The *beel* has complicated hydrological behaviour, with total inundation during the monsoon and partial drying during the pre-monsoon, causing water shrinkage (Pal and Akoma, 2009). It occurs in the riverine floodplain of the Ganga-Bhagirathi River system. Two small and low-gradient streams, Bansloi and Pagla originating from the Santhal-Pargana highland of the Chotonagpur plateau drain into the *beel* (Mondal, 2012).

Sample collection

The *beel* was sampled every month from December 2020 to November 2021. Fish samples were taken in the morning hours (7.00 – 9.00 AM) using gears such as cast nets, gill nets, drag nets, push nets, box traps and hook and lines. Fish specimens collected were identified (Talwar and Jhingran, 1991) on the field itself and individually each species was enumerated to ascertain the species composition, abundance and diversity. Fish species that could not be identified were cleaned thoroughly, preserved in 10% formalin and brought to the laboratory for further identification (Talwar and Jhingran, 1991; Froese and Pauly, 2020). The binomial nomenclature and systematic position were followed as per the Catalogue of Fishes of California Academy of Sciences (Fricke *et al.*, 2022). The fish were categorised into four groups (modified after Odyuo and Nagesh, 2012; Pandit *et al.*, 2021) based on their frequency of occurrence *viz*., most abundant (++++; recorded in 12 sampling months), common (+++; recorded in 10-11 sampling months), moderate (++; recorded in 8-9 sampling months); rare (+; recorded in 6-7 sampling months). Fishery importance of the fish species, feeding habits, trophic level and IUCN Red List status was noted down from available literature (Chutia *et al.*, 2018; Sandhya *et al.*, 2019; Froese and Pauly, 2020; IUCN, 2022).

Species diversity indices

Species richness index (d) or Margalef's index

The species richness index (d) or Margalef's index (Margalef, 1958) was used to evaluate the community structure using the following formula.

$$\boldsymbol{d} = (\boldsymbol{S} - \mathbf{1}) / \mathbf{ln} \boldsymbol{N}$$

where 'S' is the number of species in a population and 'N' is the total number of individuals in 'S' species.

Simpson diversity index (1- λ')

Simpson diversity index (Simpson, 1949), one of the most used indices to measure biodiversity, was calculated as

$$\mathbf{1} - \boldsymbol{\lambda}' = \mathbf{1} - \sum \boldsymbol{n}(\boldsymbol{n} - \mathbf{1}) \,/\, \boldsymbol{N}(\boldsymbol{N} - \mathbf{1})$$

where, 'n' is the total number of individuals of a particular species and 'N' is the total number of individuals of all species.

Shannon-Wiener diversity index (H')

Shannon-Wiener diversity index (H') (Shannon and Wiener, 1949) was calculated as

$$\mathbf{H}' = - \sum_{i=1}^{s} (\mathbf{pilnpi})$$

where 'S' is the total number of species, pi=ni/N, ni is the number of individuals of a species, and N is the total number of individuals

Pielou'sevenness Index (J')

Pielou's evenness Index (J') (Pielou, 1966) measures diversity along with species richness and was calculated using the formula,

$$\boldsymbol{J}' = \boldsymbol{H}' / \mathbf{ln} \boldsymbol{S}$$

where 'H'' denotes the Shannon-Wiener diversity index and 'S' indicates the total number of species in the sample.

Diversity indices were presented season-wise viz., pre-monsoon, monsoon, post-monsoon and winter. One-way ANOVA was performed using Statistical Package for Social Sciences (SPSS) version 22.0 to determine whether there were significant differences across seasons.

Results and discussion

Ichthyofaunal diversity

Ichthyofaunal composition is presented in Table 1, along with details on trophic level, feeding habit, fisheries relevance and IUCN Red List status of each species. A total of 42 species of fish belonging to 9 orders, 21 families and 32 genera were documented during the study period. With eleven species, the Cyprinidae family was the dominant, followed by Channidae (four species) and Mastacembelidae (three species) (Figure 2). Xenocyprididae, Danionidae, Cichlidae, Bagridae, Ambassidae and Siluridae had two species each. There were some families which were the rarest, *viz*., Cobitidae, Nandidae, Gobiidae, Osphronemidae, Anabantidae, Clariidae, Heteropneustidae, Ailiidae, Synbranchidae, Belonidae, Notopteridae and Tetraodontidae, which were collectively grouped as miscellaneous. Among the 42 species recorded in the present study, 24 (57.14%) were abundantly available, 4 (9.52%) were commonly available, 9 (21.42%) were moderately available and 5 (11.90%) were rarely available. *Puntius sophore, Pethia conchonius*, *Amblypharyngodon mola* and *Mystus vittatus* were the most abundant; while *Labeo bata, Cyprinus carpio, Hypophthalmichthys molitrix, Oreochromis niloticus* and *Leiodon cutcutia* were the rarest.

Wetlands are home to a wide variety of species because of the crucial role that microorganisms play in enhancing nutrient bioavailability and hence increasing ecosystem productivity. Wetlands are therefore seen as being the habitats most suitable for ecological growth (Mohan *et al.,* 2020). Several authors have documented and described the freshwater ichthyofaunal diversity of West Bengal and their threatened status (Barman, 2007; Mogalekar *et al*., 2017). They reported between 239 and 267 different species, including both native and exotic species as well as primary and secondary freshwater forms. There is a wealth of literature on fish and fisheries in West Bengal, notably from *beels* (Sugunan *et al.,* 2000; Mondal and Kaviraj, 2009; Mistry, 2016; Ghosh and Biswas, 2017; Pal *et al.* 2018; Mohan *et al.*, 2020; Sarkar *et al.*, 2020). Number of fish species recorded by them varied between 19 in Chaltia *beel* (Sarkar *et al*., 2020) and 54 in Patan wetland (Dey, 2017) with Cyprinidae as the dominant family, which is comparable with the present study. Sugunan *et al.* (2000) opined that open *beel*s, although less productive, harbour riverine species in addition to resident species. They reported a total of 55 fish species in open *beels* and 42 fish species in closed *beels* of West Bengal. The moderate to rich fish diversity (42 species) of the Bansabati *beel* may be due to open wetland, which offers greater habitat for native fish species and enhanced access to the river (Sarkar *et al.*, 2020). The fish species found in the Bansabati *beel* and those reported in earlier studies are consistent with the species found in the Gangetic delta (Das *et al.,* 2020; Sarkar *et al.*, 2021).

In the present study, the percentage composition of carnivores was higher (48%) followed by omnivores (36%) and herbivores (17%) (Figure 3). Likewise, Pal *et al.* (2018) in Panishala *beel* and Mohan *et al.* (2020) in East Kolkata Wetlands also reported a higher percentage of carnivores (53-56.41%). The trophic level of fish varied between 2.0 and 4.5 with *Channa marulius* emerging as the top-most predator in the *beel*. The other top carnivore fish included *Xenentodon cancila* (3.9), *Nandus nandus* (3.9), *Ophichthys cuchia* (3.8), *Ompok pabda* (3.8), *Channa orientalis* (3.8) and *Channa punctata* (3.8) (Froese and Pauly, 2020). Omnivores tend to be particularly tolerant to deteriorating surroundings due to their ability to ingest food from a variety of sources in a changing ecology (Wichert and Rapport, 1998). Therefore, when a system is least disturbed, the types of species that dominate tend to be benthic feeders and carnivores rather than omnivores in comparison to a degraded site (Karr *et al*., 1986; Hughes and Oberdorff, 1998). Thus, it appears that the Bansabati *beel* was least disturbed, as evidenced by the dominance of carnivores there.

It was found that the Bansabati *beel* harbours about two-thirds of fish species important to fisheries and with potential market value for both food and ornamental uses. While studying the ichthyofaunal diversity of the Panishala *beel* in Cooch Behar, Pal*et al.* (2018) observed that 10 species (26%) were food fish, whereas 14 species (36%) were counted as food fish and ornamental side by side. The IUCN Red List (IUCN, 2022) status of fish species of Bansabati *beel* (Table 1) inferred that one species (2.38%) named *Clarias magur* was categorized as ‘Endangered’ (EN), three species, viz., *Wallago attu*, *Oreochromis mossambicus* and *C. carpio* were ‘Vulnerable’ (VU) comprising 7.14% of the listed fish (Figure 4). Three species (7.14%) were ‘Near threatened’ (NT), namely *O. pabda, H. molitrix* and *Ailia coila*. Thirty-five of the listed fish comprising 83.33% were ‘Least

Concern’ (LC). Anthropogenic stress is continuously affecting the fish fauna of wetlands, which is causing a persistent fall in their population (Carpenter *et al.*, 2011; Sarkar and Borah, 2017; Sarkar *et al.,* 2020). A decline in as many as 19 fish species was noticed in Chaltia *beel* in 2020 compared to 15 years back in the same *beel* (Sarkar *et al.,* 2020). Local fishers of the Bansabati *beel* claim that numerous fish species and their abundances have decreased over the past 2 – 3 decades; however there is no prior literature to support their claims. According to them, *Sperata aor* and *Systomus sarana* were formerly abundant in this *beel* and lost their numbers over years. *Tenualosa ilisha* was also reportedly abundant in this *beel*, which was made feasible by its connection to the Ganges before the construction of the Farakka barrage and feeder canal.

Species diversity indices

In the present study, monsoon witnessed a minimum number of 31 fish species whereas a maximum of 42 species were found during winter and post-monsoon periods. The corresponding mean values of Margalef’s richness were 4.334 and 5.423 in monsoon and post-monsoon (Table 2). Margalef's richness varied significantly (P 0.05) depending on the season: pre-monsoon and post-monsoon, monsoon and post-monsoon, winter and monsoon, and winter and monsoon. Various authors reported the index value in the range of 0.68 – 14.12 in freshwater *beels* (Rahman *et al.,* 2019; Sarkar and Saha, 2021; Kunda *et al.,* 2022) with highest values in post-monsoon in their studies. Margalef’s richness, used to evaluate community structure, generally shows deviation depending on the species number (Vyas *et al.*, 2012). Low fish diversity in open *beel*s in monsoon compared to post-monsoon may be due to the movement of certain fish species to the adjoining low-lying areas for breeding and recruitment as also observed by Mondal *et al*., (2010) and Sarkar and Saha (2021). Later, they return to the *beel* once the flood is over, thereby increasing species numbers in post-monsoon and winter periods. Macrophtye influx in open *beel* during monsoon might also hamper plankton growth and fish diversity (Sugunan *et al.*, 2000).

Simpson’s diversity index is used to calculate diversity difference in a community. Value generally ranges from 0 (low or no diversity) to 1 (high diversity) (Ali *et al.,* 2020). Therefore, the current value indicated that Bansabati *beel* has moderate to rich fish diversity. The highest Simpson diversity index value (0.918) was observed during post-monsoon and the least during pre-monsoon (0.890). Kunda *et al.* (2022) also observed highest value in post-monsoon. Different authors have reported the value from 0.610 to 0.944 in *beels* of West Bengal and Bangladesh (Ghosh and Biswas, 2017; Rahman *et al.*, 2019; Triparna *et al.*, 2021; Sarkar and Saha, 2021). There existed a significant difference ($P<0.05$) in the Simpson index between the pre-monsoon and post-monsoon seasons. The higher value of the Simpson index (0.918) in post-monsoon could be attributed to the favourable environmental conditions and reproduction of fishes during monsoon season leading to a greater assemblage (Kunda *et al.*, 2022).

Shannon-Wiener diversity index (H') is used for calculating entropy and estimating species diversity. i.e. richness and evenness. The value usually ranges between 1.5 and 3.5 for ecological and a value above 3.0 signifies higher diversity, and a generally stable and balanced habitat structure (Magurran, 2005). In the present study, pre-monsoon recorded lowest of H' (2.786) and post-monsoon witnessed the highest value (3.018) (Table 2) indicating the Bansabati *beel* has moderate to high diversity with healthy environment. The Shannon-Wiener diversity index (H') showed a significant difference (P 0.05) between the winter and pre-monsoon, winter and monsoon, pre-monsoon and post-monsoon, and monsoon and post-monsoon seasons. Similarly, highest value during post-monsoon was reported by Mondal *et al.* (2010), Sarkar *et al.* (2020), Sarkar and Saha (2021), Triparna *et al.* (2021) in *beels* of West Bengal and Kunda *et al.* (2022) in wetland of Bangladesh. Nevertheless, with the exception of Triparna *et al.* (2021), the majority of them recorded the lowest value of H' during the monsoon, which is consistent with the present findings. During pre-monsoon, the shrinkage of wetlands leading to rise in temperature and reduction in oxygen may expose the fish to stress, thereby leading to mortality (Sarkar *et al*., 2020). It was also noted during the study and has previously been documented by earlier researchers (Pal and Akoma, 2009) that Bansabati beel shrank during the pre-monsoon months. This could have caused a decrease in individuals and a corresponding decrease in H' value. It is also supported by low value of evenness index observed in the present study during pre-monsoon.

Evenness, a metric used to determine relative diversity, has a high value when all species in a population are uniformly spread (Aziz *et al.*, 2021). Pielou's evenness (J') value usually ranges from 0 (no evenness) to 1 (complete evenness). Previous studies have found moderate to high evenness in several *beels*, with values ranging from 0.561 to 0.951 (Kaur *et al.*, 2017; Aziz *et al.*, 2021; Dua and Parkash, 2009), which is consistent with the findings of the current study. In comparison to winter and pre-monsoon seasons, monsoon and post-monsoon periods had relatively higher levels. Higher values of evenness index during post-monsoon are also reported by earlier researchers (Triparna *et al.*, 2021; Sarkar and Saha, 2021; Kunda *et al.*, 2022). There were no significant seasonal changes (P>0.05), indicating that the species were distributed rather evenly throughout the *beel* all year long.

Conclusion

The information generated in this study will serve as a baseline which could be used for conservation and management planning and developing adaptation strategies in future. The Bansabati beel has a tremendous potential for fisheries and has a moderate to rich fish variety. Rich native and decorative ichthyofauna, on the other hand, is steadily disappearing and necessitates scientific intervention for long-term ecological advantages.

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Table 1. Ichthyofaunal diversity of Bansabati *beel* recorded during the study period

Order	Family	Scientific name	English common name	Local name	Feeding habitat	Trophic level	Fishery importance	IUCN Red List status	Frequency
Cypriniformes	Cyprinidae	*Labeo bata* (Hamilton,1822)	Bata	Bata	H	2.0±0.00	FF, CI	LC	+
		Labeo rohita (Hamilton,1822)	Roho labeo	Rohu/rui	H	2.2±0.12	FF, CI	LC	++++
		Labeo catla (Hamilton,1822)	Catla	Catla	H	2.8±0.22	FF, CI	LC	++++
		Cirrhinus mrigala (Hamilton,1822)	Mrigal	Mrigal	O	2.2±0.20	FF, CI	LC	++
		Labeo calbasu (Hamilton,1822)	Orange fin labeo	Kalbose	O	2.0±0.00	FF, OF, CI	LC	+++
		Pethia ticto (Hamilton,1822)	Ticto barb	Chena puthi	O	2.2±0.00	FF, OF, CI	LC	++
		Labeo gonius (Hamilton,1822)	Kuria labeo	Kursa	H	2.0±0.00	FF, CI	LC	++++
		Cyprinus carpio Linnaeus, 1758	Common carp	American rui	O	3.1±0.00	FF, CI, Ex	VU	+
		Systomus sarana (Hamilton, 1822)	Olive barb	Sarpunti	O	2.9±0.20	FF, OF, CI	LC	++
		Puntius sophore (Hamilton, 1822)	Pool barb	Jatpunti	O	2.6±0.10	FF, OF	LC	++++
		Pethia conchonius (Hamilton, 1822)	Rosy barb	Kunchopunti	O	2.9±0.33	FF, OF	LC	++++
	Xenocyprididae	*Hypophthalmichthys molitrix* (Valenciennes,1844)	Silver carp	Silver Carp	H	2.0±0.00	FF. CI, Ex	NT	+
		Ctenopharyngodon idella (Valenciennes, 1844)	Grass carp	Grass carp	H	2.0±0.00	FF,CI, Ex	LC	++
	Danionidae	*Rasbora daniconius* (Hamilton, 1822)	Flying barb	Danrica	O	2.4±0.10	FF, OF	LC	++++
		Amblypharyngodon mola (Hamilton, 1822)	Mola carplet	Mourala	H	3.2±0.40	FF, CI	LC	++++
	Cobitidae	*Lepidocephalichthys guntea* (Hamilton, 1822)	Guntea loach	Guntea	O	2.7±0.20	FF, OF	LC	++++
Cichliformes	Cichlidae	*Oreochromis mossambicus* (Peters, 1852)	Mozambique tilapia	Tilapia	O	2.2±0.00	FF, CI	VU	++
		Oreochromis niloticus (Linnaeus, 1758)	Nile tilapia	Nilotica	O	2.0±0.00	FF, CI	LC	+
	Ambassidae	*Chanda nama* Hamilton, 1822	Elongate glass perchlet	Kath chanda	C	3.6±0.54	FF, OF, CI	LC	++++
		Parambassis ranga (Hamilton, 1822)	Indian glassy fish	Rangachanda	C	3.5±0.32	FF, OF, CI	LC	++++
Siluriformes	Heteropneustidae	*Heteropneustes fossilis* (Bloch, 1794)	Stinging catfish	Singhi	C	3.6 ±0.30	FF, OF, CI	LC	++++
	Clariidae	*Clarias magur* (Hamilton, 1822)	Philippine catfish	Magur	C	3.4±0.50	FF, OF, CI	EN	++++
	Bagridae	*Mystus vittatus* (Bloch, 1794)	Striped dwarf catfish	Tengra	C	3.1±0.10	FF, OF, CI	LC	++++
		Sperata aor (Hamilton, 1822)	Long-whiskered catfish	Aormach	C	3.6±0.53	FF, OF, CI	LC	++
	Siluridae	*Wallago attu* (Bloch & Schneider, 1801)	Wallago	Boal	C	3.7±0.56	FF, OF, CI	VU	++++
		Ompok pabda (Hamilton, 1822)	Pabdah catfish	Pabda	C	3.8±0.60	FF, OF CI	NT	+++
	Ailiidae	*Ailia coila* (Hamilton, 1822)	Gangetic ailia	Banspata	O	3.6±0.60	FF, CI	NT	++++

Order	Family	Scientific name	English common name	Local name	Feeding habitat	Trophic level	Fishery importance	IUCN Red List status	Frequency
Synbranchiformes	Mastacembelidae	*Mastacembelus armatus* (Lacepede, 1800)	Zig-zag eel	Ban	C	2.8±0.27	FF, OF, CI	LC	++
		Macrognathus aral (Bloch & Schneider, 1801)	One-stripe spiny eel	Gochi	C	3.1±0.33	FF, OF, CI	LC	++++
		Macrognathus pancalus Hamilton, 1822	Barred spiny eel	Pankal	O	3.5±0.51	FF, OF	LC	++++
	Synbranchidae	*Ophichthys cuchia* (Hamilton, 1822)	Cuchia	Kuchha	C	3.8±0.64	FF, OF	LC	++
Osteoglossiformes	Notopteridae	*Notopterus notopterus* (Pallas, 1769)	Bronze featherback	Folui	C	3.5±0.00	FF, OF, CI	LC	++++
Beloniformes	Belonidae	*Xenentodon cancila* (Hamilton, 1822)	Freshwater garfish	Bok Mach	C	3.9±0.62	FF	LC	+++
Tetraodontiformes	Tetraodontidae	*Leiodon cutcutia* (Hamilton, 1822)	Ocellated puffer fish	Cutcutia/ tapa	O	3.3±0.20	OF	LC	+
Gobiiformes	Gobiidae	*Glossogobius giuris* (Hamilton, 1822)	Tank goby	Belay	C	3.7±0.20	FF, OF, CI	LC	+++
Anabantiformes	Channidae	*Channa orientalis* Bloch & Schneider, 1801	Walking snakehead	Cheng	C	3.8±0.59	FF, EX	LC	++
		Channa punctata (Bloch, 1793)	Spotted snakehead	Lata	C	3.8±0.70	FF, CI	LC	++++
		Channa striata (Bloch, 1793)	Striped snakehead	Shol	C	3.4±0.45	FF, OF	LC	++++
		Channa marulius (Hamilton, 1822)	Great snakehead	Gajar/ Shal	C	4.5±0.80	FF, OF, CI	LC	++++
	Anabantidae	*Anabas testudineus* (Bloch, 1792)	Climbing perch	koi	C	3.0±0.40	FF, OF	LC	++++
	Nandidae	*Nandus nandus* (Hamilton, 1822)	Gangetic leaf fish	Veda	C	3.9±0.63	FF, OF, CI	LC	++++
	Osphronemidae	*Trichogaster fasciata* Bloch & Schneider, 1801	Banded gourami	Kholisa	O	3.1±0.30	FF, OF	LC	++++

FF - Food fish; OF - Ornamental fish; CI - Commercially important; Ex - Exotic; H - Herbivore; O - Omnivore; C - Carnivore; IUCN = International Union for Conservation of Nature and Natural Resources; EN = Endangered; VU = Vulnerable; NT = Near Threatened; LC = Least Concern; ++++= Most abundant; +++ = Common; ++= Moderate += Rare.

Table 2. Species diversity indices in different seasons in Bansabati *beel*

Season	Margalef's richness index	Simpson's diversity index	Shannon and Wiener index	Pielou's evenness index
Pre-monsoon	4.388^{a}	0.890^{a}	2.786^{a}	0.795^{a}
Monsoon	4.334^{a}	0.905^{a}	2.790^{a}	0.817^{a}
Post-monsoon	5.423^{b}	0.918^{ba}	3.018^{b}	0.814^{a}
Winter	5.290^{b}	0.905^{a}	2.977^{b}	0.796^{a}

Mean values bearing different superscripts under each column vary significantly (P<0.05)

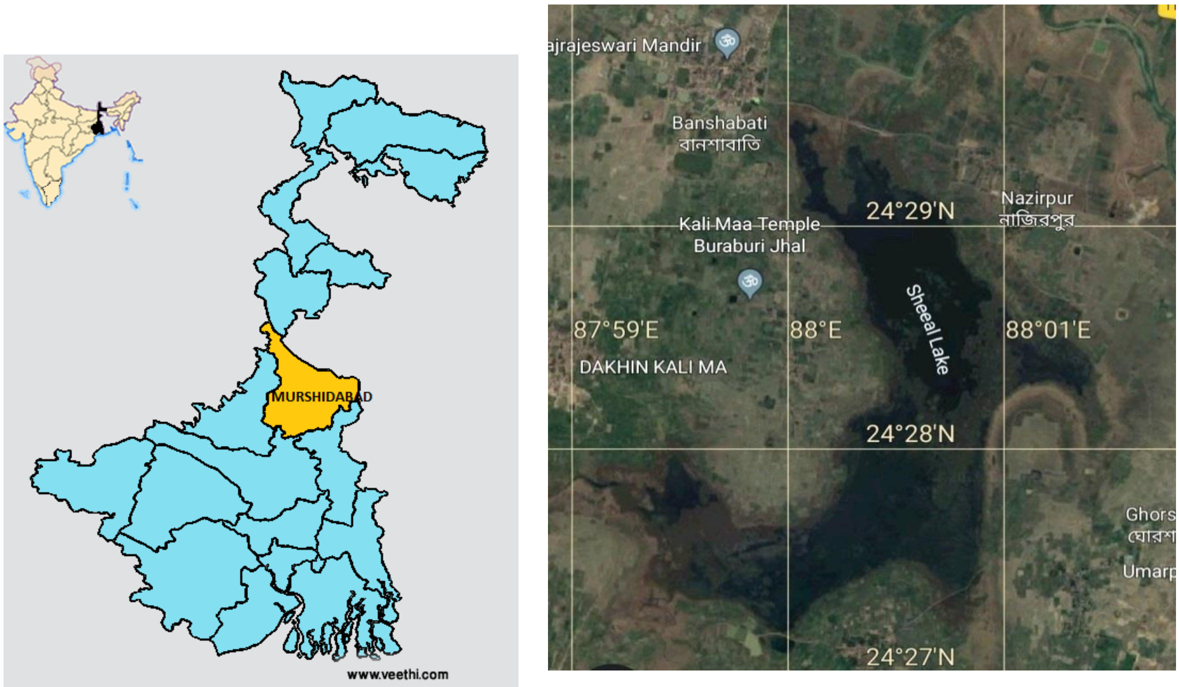

Figure 1. Location of Bansabati *beel* (Source: Google Earth)

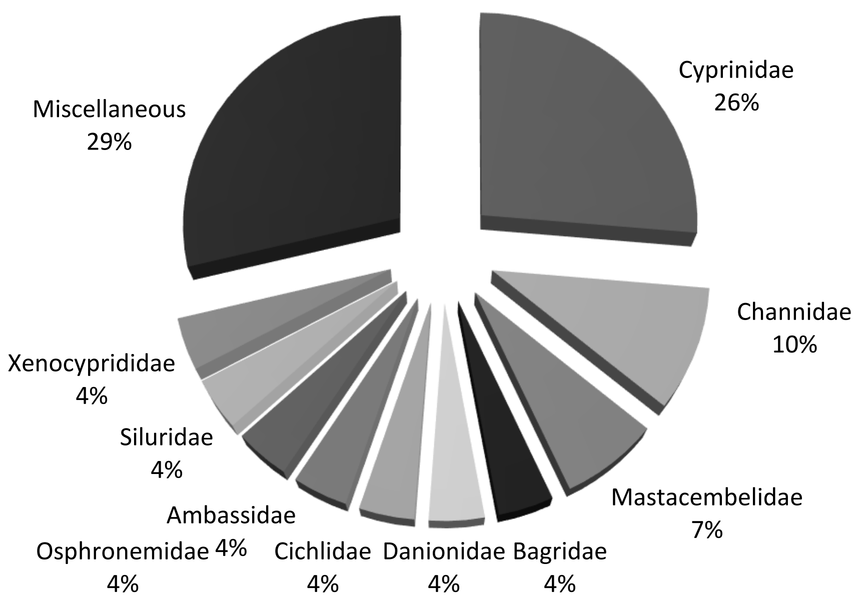

Figure 2. Family-wise distribution of fish species in Bansabati *beel*

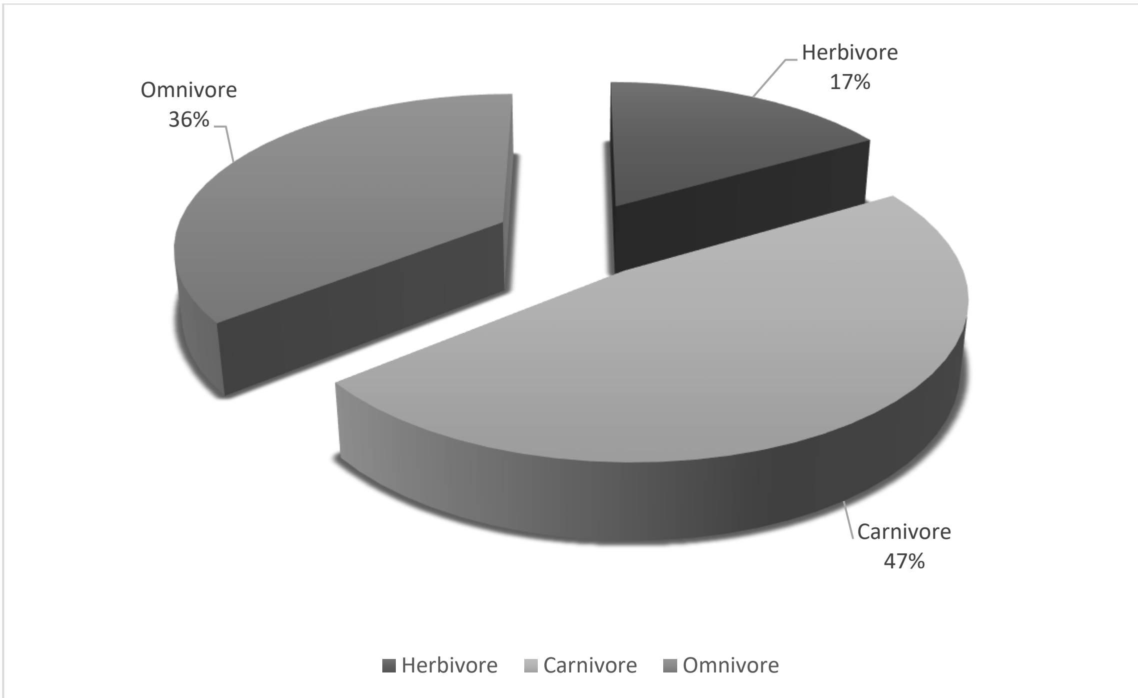

Figure 3. Composition of fish species with different feeding habits in Bansabati *beel*

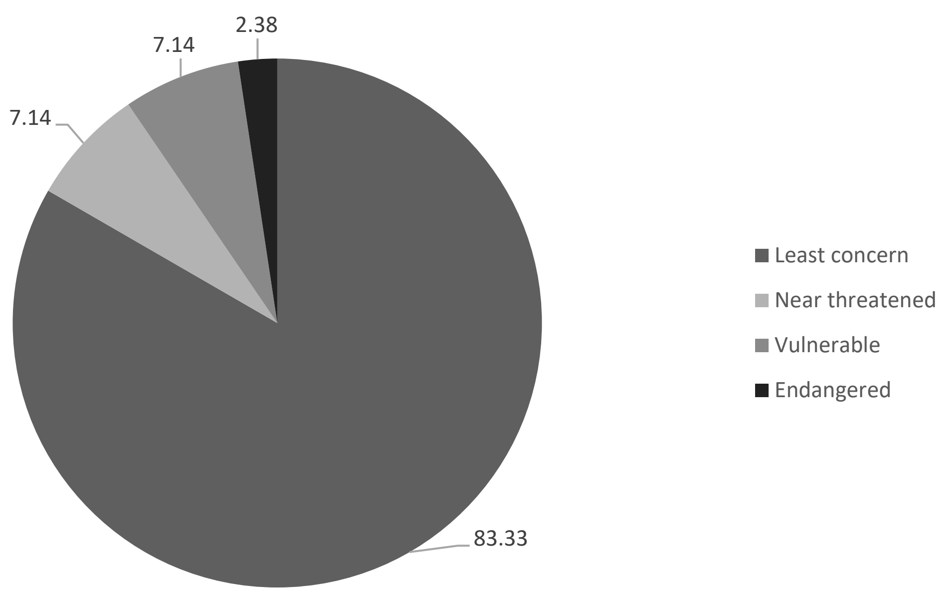

Figure 4. The IUCN Red list status of the fish of Bansabati *beel*

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SUMMARY

I am Arghya Kamal Mondal, a full-time research scholar of Life Science, Dept. of Fisheries Resource Management, Faculty of Fishery Sciences, West Bengal University of Animal and Fishery Sciences, Chakgaria, Kolkata-700094. My research objective is Ichthyofaunal diversity and ecological status of Bansabati beel.

Personal Details

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- **Mother's Name**
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Education

- B. Sc. (Hons.) in Zoology, University of Calcutta, 2016
- M. Sc. in Zoology with Fisheries Special, 1st Class, University of Kalyani. 2018
- During research on Life Science

Experience

- Research Fellow, *Dept. of Fisheries Resource Management, West Bengal University of Animal and Fishery Sciences, Chakgaria, Kolkata-700094*
- Duration: September 2018 to December 2022
- Title of Research Works: **Ichthyofaunal diversity and ecological status of Bansabati beel, Murshidabad district, West Bengal**

Highlights

- Hard-working
- Research attitude
- Operability and commitment
- Ability to motivate staff
- Resistance to stress
- Good manners

Publication

Sl. No.	Title of the paper	Authors	Title of the Journal (NAAS)	Remarks/Status
1.	Ichthyofaunal diversity of Bansabati beel - An open wetland in Murshidabad, West Bengal	Arghya Kamal Mondal, Nagesh T. Srinivasan, Sudhir Kumar Das, Samarendra Behera, Bipul Kumar Das, T. Jawahar Abraham	Journal of Inland Fisheries Society of India (5.71)	**Accepted**
2	Evaluation of fish based index of biological integrity of a floodplain wetland of the Gangetic basin, West Bengal, India	Arghya Kamal Mondal, Nagesh T. Srinivasan, T. Jawahar Abraham, Samarendra Behera, Sudhir Kumar Das, Sagarika Das, Aishika Banerjee	Tropical Ecology (6.85)	**Communicated (under review)**

Scientific Activities

- Completed 21 days National Training Course (NTC-2021) on Recent Advances in Fisheries and Aquaculture Technology for Sustainable Rural Development, jointly organized by WBUAFS, Kolkata, and National Agriculture Development Cooperative (NADC), Baramulla, J & K, during May 18-June 07, 2021.
- Completed 28 days Certificate Course on “Aqua Clinics & Aquapreneurship Development Programme”, from 20-01-2020 to 16-02-2020, conducted by Director of Research, Extension & Farms, WBUAFS, Kolkata, in partnership with National Institute of Agricultural Extension & Management (MANAGE), sponsored by National Fisheries Development Board (NFDB).
- Attended the workshop on Animal Care, Handling, and Management during March 23-31, 2019 organized by the Dept. of Zoology & Institutional Animal Ethics Committee, University of Kalyani, Kalyani.
- Attended the 2nd Regional Science and Technology Congress (Southern Region, 2017, organized by the University of Kalyani. Dept of Higher Education Science & Technology, and Dept. of Biotechnology, Govt. of India during December 14-15, 2017.

Extra-Curricular Activities

- 5th Year Diploma in "Tabla" from Bangiya Sangeet Parishad
- 5th Year Diploma in "Rabindra Sangeet" from Pracheen Kala Kendra, Chandigarh

Hobbies

- Singing
- Writing
- Drawing