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Temporal and Spatial Dynamics of Plankton Communities in the Lower Haora River, Tripura, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Planktons are significant bioindicator of ecosystem functioning, knowledge of the seasonal fluctuation in the plankton population in riverine waters of Indian subcontinent is rather limited. In the present study, analysis regarding spatio-temporal variations based on different multivariate statistics and indicator value analysis is done along with analysis of community structure of plankton assemblages. A total of 46 plankton taxa out of which 38 phytoplankton and 8 zooplankton taxa have been identified based on examination of samples taken from four locations over three sampling seasons. The primary phytoplankton families that involve Chlorophyceae, Bacillariophyceae, Cyanophyceae, Euglenophyceae and Composopogonophyceae. Chlorophyceae dominated the phytoplankton population, followed by Bacillariophyceae and Cyanophyceae. The plankton abundance was recorded highest in spring, followed by winter, and the least reported in monsoon season. The high average percent contribution of *Aulacoseira, Oscillatoria,* and *Spirogyra* species is well represented through SIMPER analysis. In addition, the Shannon–Wiener index (H) was calculated to determine plankton diversity, and Pielous' Evenness index (E) was calculated to

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determine individual distribution within a community whereas Margalef's Richness index showed species richness of the study area. This qualitative and quantitative study will aid future research on the occurrence of plankton as well as the more trustworthy information generation on fish diet and feeding behaviors. The condition of planktons as bioindicators would indirectly provide an estimation of the ecosystem's natural state or amount of pollution.

Keywords: Plankton; spatio-temporal; variation; abundance; seasonal.

1. INTRODUCTION

India is one of the world's major hubs for biodiversity comprising of two of the world's eighteen 'Biodiversity hotspots' located in the Western Ghats and the Eastern Himalayas. Geographically, Northeast India is concealed deep in one of the most biodiversity-rich regions of the world. Tripura is the third smallest state in India and is blessed with several small and major rivers. Khowai, Manu, Haora, Muhuri, and Gomati are some major rivers of Tripura. Haora is depicted as the lifeline of Agartala, the capital of Tripura. The river originating from the eastern side of Baramura hill range flows westward through the alluvial plains, skirting the southern periphery of Agartala before entering Bangladesh Bhattacharya and Saha [1].

The Haora River is one of the major river of the West Tripura District of Tripura, native people of the state also refer to it as Saidra (in Kokborok language) Bandopadhyay and De 2018. The River Haora originates in the Baramura hills in West Tripura district. After passing through Chandrasadhubari, Champak Nagar, Debendranagar, Jirania, Ranirbazar, and Pratapgarh, the river reached Agartala and eventually met the river Titas in Bangladesh. With several lower-order streams, the river's flow length in Indian territory is 53 kilometers and the basin area is 570 square kilometers. This river has an annual flow of 36,032 m^3 Bandopadhyay and De 2018.

Planktons are microscopic organisms that reside in watery environments, both salty and fresh, thus the plankton are at the mercy of currents more so than fish and other larger organisms. Plankton, composed of both phytoplankton and zooplankton, plays a crucial role in fish growth, and are primary producers that sustain fisheries as nourishment in the food web Rahman and Jewel [2]. They provide food for a variety of species such as fish, whales, shrimp, snails, crabs, and jellyfish in any well-balanced ecosystem. Nutrient enrichment through, riverine inputs and discharge from anthropogenic activities can significantly alter the phytoplankton growth and in turn, affect the zooplankton grazing pressure. Therefore, plankton assemblages are usually helpful in assessing the water quality as they quickly respond to the environmental changes and, hence; act as ecological indicators of an ecosystem Hays et al. [3].

Rivers play a vital role in making an urban landscape during the formation and development of the city. Numerous anthropogenic pollutants have been released into urban rivers due to the continued growth of cities around the world and human activity, which has resulted in serious environmental issues like declining water quality, destruction of the environment, loss of biodiversity, and more. Swaney et al. [4]. Seasonal variations in ecological parameters such as DO, salinity, temperature, and nitrate have a major impact on plankton distribution and abundance Chang et al. [5]. Regarding temporal and spatial variability, the limitations of predicting plankton species abundance are a subject of special concern. As an inevitable implication, the investigation of a water body's plankton community's composition, variety, and abundance can be utilized as a tool for monitoring and evaluating water quality, till today very little information is available on the accessibility of the abundance, diversity, composition and spatial variation of phytoplankton and zooplankton in the Haora River. However, the planktonic information of the Haora River is very crucial for the development of the fisheries sector in Tripura. The goals of this study are twofold: first, to provide estimates of plankton abundance with known error and minimal sampling effort; and second, to provide some insight into the characteristics of the plankton distribution.

2. MATERIALS AND METHODS

The length of the river Haora in Indian part is 53 km (Fig. 1). The basin is situated between the latitudes of 23˚37′ N and 23˚53′ N and longitudes of 91˚15′E and 91˚37′ E with an area of about 457.97km^2. (TSPCB, 2012). Four separate sites were chosen for this investigation,

along the lower reaches of the Haora River. The research includes along 53 kilometre stretch of the river from Ranirbazar to Champaknagar. Collection of plankton was made by filtering 100 litre of water sample each time. Sampling points remaining same throughout the study period for plankton analysis. The sampling was carried out between November 2022 and September 2023, and it spanned three seasons: winter, spring and monsoon. The samples are taken at monthly intervals throughout the early hours preferably (6.30 to 11.30 o'clock) from four sampling stations: Site I, Site II, Site III and Site IV.

Plankton samples were collected from the surface with minimal disturbance and filtered in a using a plankton net with a mesh size of 25 µm. The final volume of the filtered sample was stored in glass vial and labelled mentioning the time, date and place of sampling. Samples are collected in one litre plastic cans and preserved in 5% formalin solution for further laboratory works kept in the dark and under refrigeration.

2.1 Plankton Identification

Phytoplankton identification and quantification were done using Sedgewick-Rafter counting slides. Prior to observation the samples were homogenised by gently agitating the sample bottle. From a well-mixed sample, 1 ml was dispensed into the counting cell and viewed under a compound microscope at 4X and 10X magnifications. Plankton taxa are identified following Needham and Needham [6] Adoni [7] APHA [8] and Kumar A. [9].

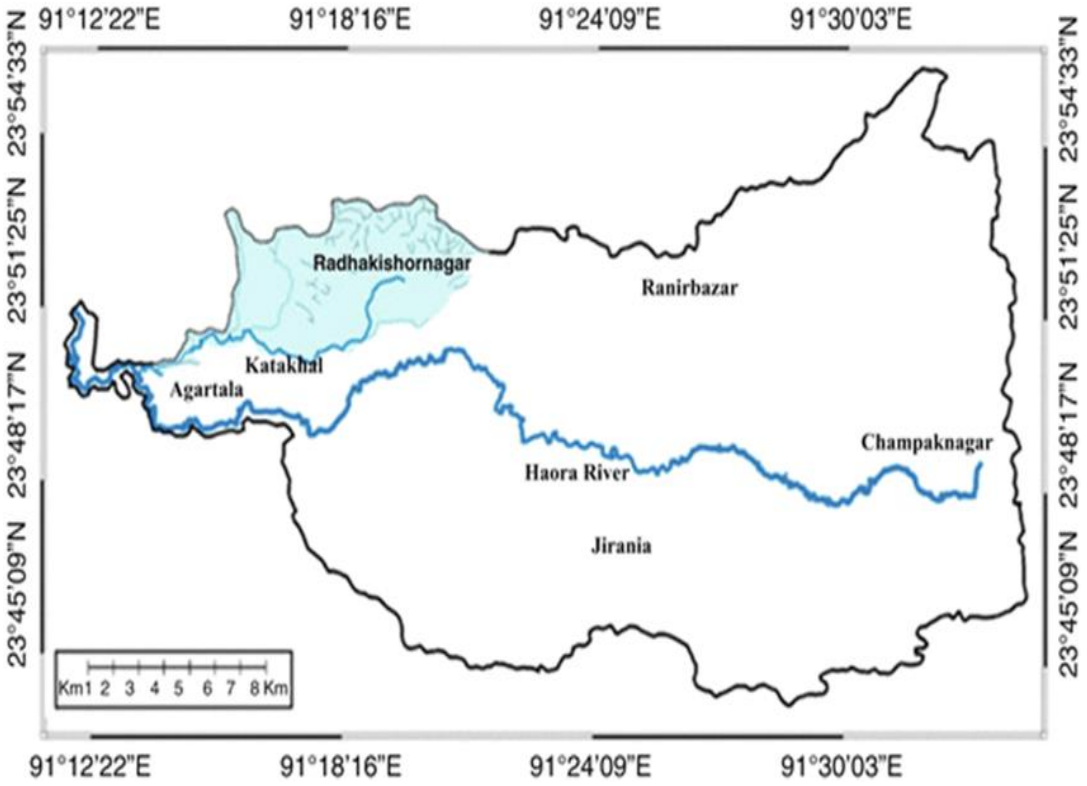

Fig. 1. Map showing study location
Photo credit: Sarkar, K., & Majumder, M. [30].

Table 1. Sampling sites for the study

Sl. No.	Sampling Sites	Latitude	Longitude	Remark
1	Site I	Lat N23º82'83.05"	Lon E91º36'46.31"	Ranirbazar
2	Site II	Lat N23º84'54.16"	Lon E91º34'07.8"	Khayerpur
3	Site III	Lat N23º81'64.12"	Lon E91º43'80.52"	Jirania
4	Site IV	Lat N23º80'31.88"	Lon E91º48'92.94"	Champaknagar

2.2 Counting of Plankton

Plankton was counted using a Sedgewick Rafter cell. The plankton per litre of original water was estimated applying the following formula Stirling [10].

$$N = A * 1000 * C / V * F * L$$

Here, N=Number of plankton cells or units L-1 of original water

A= Total number of plankton counted
C= Volume of final concentration of the sample in ml
V= Volume of a field = 1 mm3
F= Number of the field counted
L= Volume of original water in litre

2.3 Data Analysis

This study determines the diversity of plankton species using three Diversity analysis tools: Shannon-Weaver index (H′) Shannon and Wiener [11] Evenness by Pielou's index (J') Pielou, [12] and Species richness index (d) Margalef, [13].

Shannon- Wiener diversity index (H')

$$H' = - \sum (pi * \log pi)$$

Where, H' = Shannon-Weaver index, pi = ni/N, (ni = no. of individual of species, N = Total number of individuals

Species richness index (d)

$$\mathbf{d} = (\boldsymbol{S} - \mathbf{1})/ \mathbf{L}\text{og } N$$

Where, d= Species richness index, S= Number of species in a population, N= Total number of individuals in S species

Evenness index (J')

$$\mathbf{J}' = \mathbf{H}'/\mathbf{H}' \text{ (max)}$$

Where, J'= Evenness or Equitability index, H'= Shannon and weaver index, H′ (max) = the theoretical maximum value for H' if all species in the sample were equally abundant. H' (max) = ln

2.4 Statistical Analysis

All the graphs and statistical analysis was carried out using Microsoft Excel (MS Office-2013), PRIMER-version 6.0 software and SPSS software.

2.5 Cophenetic Correlation Coefficient

A clustering method operates on some measure of resemblance (similarity/dissimilarity/distance) among objects. It uses those resemblances to produce a result from dendrogram or some other result. Cophenetic correlation is a measure of how well the clustering result matches the original resemblances. correlation coefficient is a metric for how well a dendrogram retains the pair-wise distances between unmodeled data points.

3. RESULTS AND DISCUSSION

3.1 Community Structure and Composition of Plankton

A total of 38 phytoplankton and 8 zooplankton genera have been identified through examination of samples collected from four sites over three seasons. The phytoplankton genera belonging to five major classes viz., Chlorophyceae, Bacillariophyceae, Cyanophyceae, Eugleno phyceae and Composopogonophyceae are found in the study. Chlorophyceae (16 genera) dominated the phytoplankton population followed by Bacillariophyceae (13 genera), Cyanophyceae (5 genera), Euglenophyceae (2 genera) and Composopogonophyceae (1 genera). In zooplankton the family cyclopidae (3 genera) contributed the most. The zooplankton genera include *tortanus*, *moina*, *cyclops*, *megacyclops*, *acanthocyclops*, *euterpina*, *paracalanus* and *oithona* species. The highest numbers of phytoplankton genera are being recorded during the spring season and the lowest during the monsoon season. Bacillariophyceae contributed the highest in the phytoplankton community (46.6%) followed by Chlorophyceae (33.07%), Composopogono phyceae (9.05%), Cyanophyceae (8.92%) and Euglenophyceae (2.35%). Among zooplanktons, cyclopidae family (56.39%) comprising of *cyclops, megacyclops* and *acanthocyclops* contributed the most followed by Tachiididae family comprising of *Euterpina* species (14.07%).

During the entire study period, *Composopogon* (9.05%), *Synedra* (8.08%), *Fragillaria* (8.01%), *Ulnaria* (7.62%), *Navicula* (4.65%) species contributed the most. Among zooplanktons, *Cyclops*, *Megacyclops*, *Acanthocyclops* and *Euterpina* species are dominant. Among Bacillariophyceae, *Synedra* and *Fragillaria* species have contributed the most among the group. Similarly, *Spirogyra, Oedogonium* and

Cosmarium dominate the Chlorophyceae. In the study period through three seasons, the Site I and Site II have a stronghold of *Synedra* sp., followed by *Ulnaria* and *Fragillaria* species. However, the Site III and Site IV have been largely dominated by *Composopogon* spcies. The Bacillariophyceae percent contribution was highest (48%) during the winter season while Euglenophyceae are recorded rarely (3.81%) in that season. Bacillariophyceae (42.3%) and Chlorophyceae (38.7%) were recorded maximum in spring season. While in monsoon season, the dominant group was Bacillariophyceae (59.09%).

Three separate seasons are included for analysing temporal diversity indices: winter, spring and monsoon. There is an apparent temporal trend of fluctuation in the Shannon-Wiener diversity index (H'), Pielou's evenness index (J'), or Margalef richness index (d) values.

The Shannon-Wiener diversity index (H') is a diversity metric that takes into account both species richness and relative abundances. The Shannon diversity index (H) is a measure of a community's species variety. When a community dominated by a few species is regarded to be less varied than a community with a similar abundance of many species. The Shannon wiener diversity index is seen to be higher in spring and lowest in monsoon.

Species evenness is described as the even distribution of species in an environment. The diversity of species grows as the evenness value rises. Monsoon season has the highest species evenness followed by spring and monsoon.

Species richness is the most basic measure of biodiversity, referring to the number of distinct species identified in a given ecological region without taking into account species abundance. Although it seeks to correct for sampling effects, the Margalef index measures species richness and is very sensitive to sample size Magurran [14]. The Margalef Species Richness Index (d) calculates the number of common and uncommon species. When the number of species in a population grows, the variety of that population grows. Spring season has considerably high species richness followed by winter and monsoon.

Table 2 Temporal distribution of diversity indices

Diversity indices	Winter	Spring	Monsoon	Mean
H'(Shannon Wiener diversity index)	2.7285	2.84125	2.08425	2.55133
j'(Pielous'evenness index)	0.88465	0.8913	0.9292	0.90171
d (Margalefs' richness index)	1.857525	1.92525	0.9608	1.58119

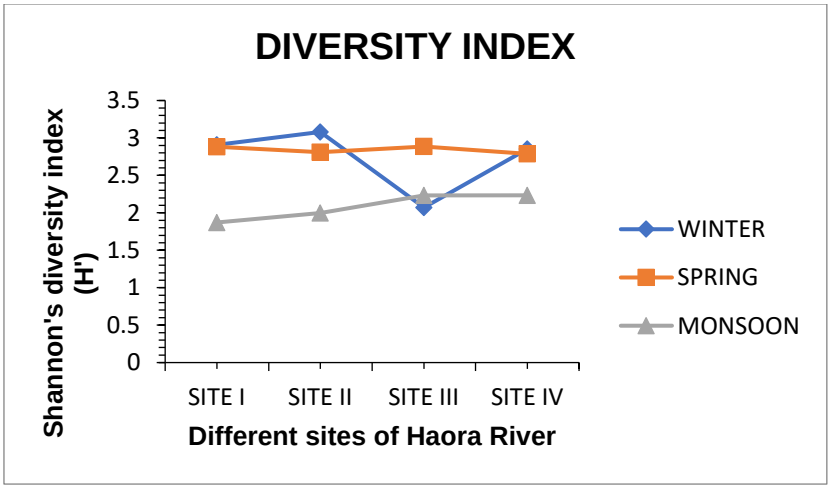

Fig. 2. Spatio-temporal variation of Shannon wiener diversity index

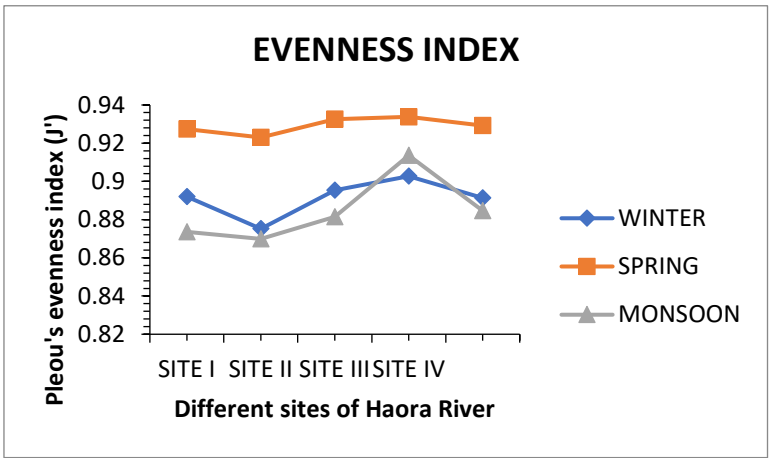

Fig. 3. Spatio-temporal variation of evenness index

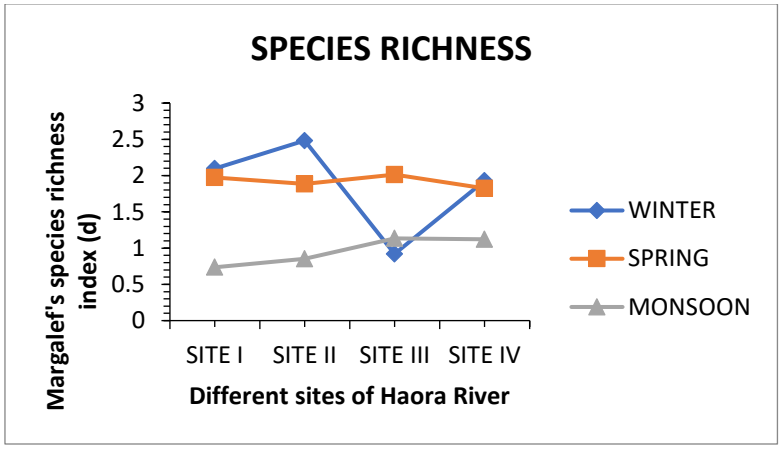

Fig. 3 Spatio-temporal variation of richness index

Table 3. Season wise cophenetic correlation coefficient

Sl. No.	Season	Cophenetic correlation coefficient
1	Winter	0.9355
2	Spring	0.8824
3	Monsoon	0.9392

3.2 Cophenetic Correlation Coefficient

A clustering method operates on some measure of resemblance (similarity/dissimilarity/distance) among objects. It uses those resemblances to produce a result from dendrogram or some other result. Cophenetic correlation is a measure of how well the clustering result matches the original resemblances. So, as an example, similarities among samples are clustered using a method like Unweighted Pair group Average (UPGMA) to produce a dendrogram. The distances among samples are calculated through the dendrogram (actually to a common node, but the idea holds) to give cophenetic distances. The between-sample original resemblances are correlated with the cophenetic distances to give cophenetic correlation. If the value is high (near 1) the clustering result is an excellent representation of the original distances, if it is <<1 then it is not. The cophenetic correlation coefficient is highest in the monsoon season, followed by winter and spring season.

The chlorophyll percentage is considerably highest in spring followed by winter and monsoon and the similar trend has been recorded in Mishra et al. [15]. The chlorophyll content is comparatively higher in site III (Jirania) and site IV (Champaknagar) than site I (Ranirbazar) and

site II (Khayerpur). Chlorophyll-*a* constitutes the main photosynthetic pigment of phytoplankton, gives the potential of primary productivity which in turn supports the biomass, biodiversity and carrying capacity of the system. It has been found that the water samples taken for examination were found to be most turbid with the highest suspended solids during the monsoon period, similar to the findings of Dash et al. [16]. Nutrient levels are recognized as the significant determinant of riverine productivity and their spatio-temporal variation can play an important role by influencing the process of competition and community structure as well as trophic dynamics in the riverine environment. In the present study, high monsoonal value of ammonia and nitrite could be influenced by organic matter received from the catchment area.

An aggregate of 38 phytoplankton and 8 zooplankton genera have been identified through examination of water samples at four sites over three seasons. In this inspection, we discovered that species from the Bacillariophyceae family were dominant over others. Similar trend has been seen in Rupsha-Pashur; Khalpatua-Arpangachia; and Bhola-Baleswar river systems, which showed the dominance of Bacillariophyceae having 99 species from 41 genera. Another study reveals the similar pattern that is in Seasonal variation of phytoplankton in Lake Simenit reveals in phytoplankton, the most widespread group of algae was Bacillariophyta that composes of 41% of the total taxa Ersanl and Gonulol [17].

Phytoplankton composition was more diverse during post-monsoon period, especially diatoms (bacillariophyceae) found to be more dominant group than the others. It has been revealed that favourable environmental condition, effects of late monsoon such as upwelling and land run-off which proves suitable for the growth and proliferation of bacillariophyceae Dehradrai and Bhargava [18] Dupuis and Hann [19]. The current report of 38 taxa is higher compared to 35 phytoplankton taxa reported from Rudrasagar Lake Bharati et al. [20] 29 genera recorded from Haora river Bhattacharya and Saha, [1] and 34 phytoplankton species reported from Gomti river at Lucknow Dixit and Sharma, [21]. The phytoplankton has appeared to be both eutrophic and polymixic.

The Haora River's phytoplankton community depicts a clear seasonal pattern, with higher abundances in the spring-winter period and reduced densities in monsoon season. The high abundance of total phytoplankton during spring and winter period implies suitable physico-chemical conditions. The phytoplankton population found to be considerably low during monsoon season that is the period of high precipitation; this could be due the high turbid nature of the water in the river which in turn brings about the decline in the intensity of light that passes though the water on the upper region. In the present study, it has been shown that the water current velocity is higher in monsoon than the post monsoon period. Due to increased water flow in monsoon season which in turn affect the plankton density which becomes low as compared to winter season Dixit and Sharma, [21]. In general, the system experiences nutrient depletion shortly after monsoonal precipitation, which has a significant influence on decreasing productivity and may be the reason for lower plankton abundance Nandy and Mandal, [22].

Nandan and Aher [23] has revealed the phytoplankton genera, Oscillatoria, Scenedesmus, Navicula, Nitzschia and Microcystis which are the species found in organically polluted waters. In the current study, the similar genera were recorded in abundance which point towards the deterioration of water quality of the Haora River. Bacillariophyceae as indicators of contamination also recorded by Naz et al. [24] in river Padma in Bangladesh. The abundance of Bacillariophyceae is more prevalent in site I (Ranirbazar) and site II (Khayerpur) than site III (Jirania) and site IV (Champaknagar). It represents site IV (Champaknagar) and site III (Jirania) are comparatively less polluted than site I (Ranirbazar) and site II (Khayerpur). Haora River is less polluted in the Champaknagar and it getting polluted downstream as the river into the city area of Agartala Rani and Dutta [25]. The presence of Oscillatoria throughout the seasons in different sites of Haora River having abundance in site I (Ranirbazar) depicts the deterioration of water quality of site I than other sites of the river. The presence of Oscillatoria was indicating pollutants of biological origin which has an agreement with the findings of Gadag et al. [26].

In the present study, Aulacoseira sp. having higher percentage abundance in monsoon and post monsoon period which is supported by the study that shows Aulacoseira is a R-strategist widespread diatom, that can dominate in water

bodies under turbid conditions Hutchinson [27] Reynolds, [28]. The chlorophyceae were mostly found in abundance in spring and winter months but not found significantly during the monsoon period due to minimal light penetration caused by excessive turbidity.

Three separate seasons are used for calculating temporal variety indices: dry winter, wet monsoon and spring season. The Shannon wiener diversity index (H'), Pielou's evenness index (J'), and Richness Index (d) value has been calculated. It is a way to measure the diversity of species in a community. The Shannon wiener diversity index is denoted as **H',** higher values indicate higher diversity in the community and vice-versa. The Shannon Wiener diversity indices shown highest in spring season followed by winter season. The value ranged from 2.72 to 2.08 with a seasonal mean of 2.55. Rahaman et al. [29] recorded higher H′ value from 1.31 to 4.64 which depicts a rich diversity of plankton in the Pasur River estuary. Due to high volume of freshwater addition during high precipitation occurring in monsoon period may result in lowest Shannon-Weaver diversity index. With the increase in species diversity the evenness value also increases. Pleou's evenness index is a measure of diversity that considers both species richness and relative abundances. The evenness value was found to be higher in spring with a value of 0.92, and lower in monsoon with a value of 0.88. A similar pattern been observed in Rupsha-Pashur River with a range from 0.77 to 2.4 Rahman et al. [29]. The richness of species has been measured in the range of 0.96 to 1.85, with a seasonal mean of 1.58. The Margalef's richness index has been found higher in spring, followed by winter period while least value is observed during monsoon season [31].

4. CONCLUSION

Algal communities produce a significant amount of organic carbon in bigger rivers, provide food for planktonic consumers, and may be the primary supply of oxygen in many low-gradient rivers. Given the scarcity of data on riverine planktons in northeast India and Tripura, the current research has been undertaken to investigate the variations in plankton in the lower stretch of the Haora River in Tripura which shows there is a significant spatio temporal variation in plankton diversity and abundance across the Haora River. From the evaluation of samples obtained from four sites over three seasons, a total of 38 phytoplankton and 8 zooplankton taxa have been identified. This study found phytoplankton genera from five key classes: Bacillariophyceae, Chlorophyceae, Cyanophyceae, Euglenophyceae and Compsopogonophyceae. Bacillariophyceae had the highest generic density across all sites followed by Chlorophyceae. The diversity indices showed evident temporal trend of variation across the season. Spring and winter are the most productive seasons for this river system in terms of plankton population. The major species were *Aulacoseira*, *Oscillatoria*, *Spirogyra*, *Fragillaria*, and *Synedra*, which are produced maximum virtually all year.

The results of this study show that there are considerable spatial and temporal differences across plankton groups, which are influenced by water physicochemical characteristics. These distinct variations are probably related to both biotic and abiotic parameters in the river. Haora River is depicted as the lifeline of Agartala city because it fulfils the major demand of drinking water as well as water for other purposes of the entire population of Agartala city. It also fulfils the total demand of the families who reside near the banks of the river from Champaknagar to Bangladesh border area. So, the effect of pollution due to human intervention cannot be neglected. The intervention of pollution influenced filamentous algae justifies the study. This qualitative and quantitative analysis will be helpful in further studies regarding plankton occurrence and production of more reliable information regarding food and feeding patterns of the fishes. Reliable evidence and information regarding plankton population can help in bio-monitoring studies to determine the population status of aquatic bodies.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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